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CHAPTER 1 - GENERAL

This is a report of Phase I of the NBS project, Systems Approach to Mine Fire Safety, being conducted under sponsorship of the U.S. Bureau of Mines. The purpose of Phase I was to develop a qualitative description of the inherent fire safety/fire risk system in a coal mine. The approach consisted of the development of an event logic tree to analyze forces and countermeasures involved, and the development of a supporting state transition model to assist in identifying the states of fire development and human response potentially occurring in a mine fire.

An event logic tree and a state transition model have been developed. The development is considered interim as it is expected that additional information will cause improvements and changes during the subsequent phases of the project.

The bulk of the report, Chapters 2 through 12, constructs an event logic tree designed to divide the fire safety methodological factors that determine coal mine fire safety into related constituent parts. Chapter 13 presents a state transition model, designed to consider potential levels of fire development in coal mines.

CHAPTER 2 - EVENT LOGIC TREE APPROACH

The Event Logic Tree approach used in this study follows the general concepts of a reliability tree or a reliability network applied in a qualitative form. The general rules that would apply in a quantitative analysis have been followed. However, the state-of-the-art of data and the potential of acquiring new data is such that it is impractical to expect a truly quantitative tree covering the full breadth undertaken in this exercise. In each case, however, where quantitative data can be developed or used in part, the tree is designed to accept it to whatever degree it may be applicable to an internal tree decision or calculation.

The tree itself is a diagrammatic means of showing the complete event logic system that progressively subdivides the problem (analysis of the existent fire safety/fire risk system in mines) into smaller and smaller elements to the level at which a rational judgement can be made. The tree arrangement assists in pointing out events that must occur simultaneously versus those that can independently control the results. Thereby showing which elements can contribute most effectively to the success of the fire safety system. The tree also inherently expresses choices or tradeoffs that can be involved in this performance. The identification of events and the arrangement of gates in the tree show conditionality and situations where events are mutually exclusive. In designing the tree, the following general protocol was followed:

1. All events were kept consistent in term. In this tree, all events are expressed in terms of success in achieving the fire safety performance of the top event (Event 1.0, Fire Safety Performance).

2. The universe is maintained throughout the tree so that any lateral cut through the tree will describe the identical universe to either the top event or the entirety of the bottom events. This universe is the universe of success (or contribution) to fire safety performance. In addition, the universe of the top event is identical to the collection of all bottom events.

3. At each step, a gate factors the universe of the event above the gate into the events below the gate.

4. Conditionalities are determined and identified in the gates in the tree and in the accompanying definitions.

5. The conditionalities are expressed in unit terms, i.e., if the unit statement is used, a conditional event includes all of its conditionalities such that it can mathematically function as an independent, collective entity.

6. This system is sufficiently dimensionally consistent so that the dimensions feeding into a gate from sub-events are the same and consistent with the event being fed.

7. Each gate can be stated in a mathematical sentence covering all of the involved events including conditionalities.

8. Each event added to the tree adds understanding and potential for the intended use of the tree.

The tree progressively factors the initial or "top" event. In this tree, the top event is entitled, Fire Safety Performance, and is the measured or demanded level of prevention or limitation of harm to persons, property or functional capability. At each step of the factoring, the events necessary to achieve the higher event are deduced and analyzed to determine if success in the higher event is dependent upon simultaneous success in all of the factored events or, conversely, success in any single event. This query determines the type of gate involved.

Traditionally, event logic trees use only two types of gates "AND" and "OR". In this tree, however, the category of types of gates has been further subdivided to show inherent differences "OR" gates. Special symbols have been developed and used to separate the "OR" gates into three separate categories as follows:

a. Mutually exclusive "OR" gates (either/or, but not both).

b. Not mutually exclusive "OR" gates (either/or, or both).

c. Multi-variant relationships (i.e., probability density function), where one event is conditional on both the occurrence and magnitude of the other event.

In addition, this tree includes an approach referred to as a Function Gate. The function gate does not actually subdivide the event in probabilistic type

elements, but rather is used to lead to a special branch listing physical or behavioral elements that determine the level of performance of an event. Function gates are always at the termination of a branch of the main tree. Wherever possible, the branches relate fire phenomena or the response of people and material to fire impositions to the events in the tree.

Chapters 3 through 12, and Figures 1 through 14 lay out and analyze the Event Logic Tree.

In Chapters 3 through 12, the tree is analyzed in terms of the definition of events and the functioning of the gates. For each chapter there is a corresponding figure showing the portion of the tree being analyzed. In some chapters there are also corresponding figures showing functional branches related to the chapters. In each case, the analysis is made by following the tree from its top and at each gate moving to the left hand side of the gate. When an end event is reached in this manner, the sequence proceeds to cover all connected events, following the lines of connections, while moving from the left hand side of the page to the right hand side.

CHAPTER 3 - GENERAL EVENT LOGIC TREE (Figure 1)

For ease of handling, the coal mine Event Logic Tree has been divided into a General Event Logic Tree and a series of branches. This chapter covers the general tree. Each terminal event in the general tree is the top event of one of the separately reported branches.

Each event is identified by an arbitrary numbering system that matches the numbering system in the Event Logic Tree, followed by the title of the event. The title matches the wording in the tree. For each event, the principal element is defined and the gate leading from that event to subsequent events described.

1.0 Fire Safety Performance

Fire safety performance is the measured or demanded level of prevention or limitation of selected form(s) of harm to persons, property, or functional capability. The tree can handle all potential forms of harm (either singly or as a synergistic collection). The user of the tree or the authority overseeing its application must, however, declare the specific types of harm under consideration. The event logic tree is so designed that this event is reached only if all routes to it are brought to a common measurement of degree of success in avoidance of harm. In those instances where it is desired to use the tree at a lesser level of sophistication (e.g., probability of avoidance of harm if fire occurs), some portions of the tree rather than its total entity should be used.

Gate 1.0 - The degree of success in meeting fire safety performance objectives is the sum of degree of success in preventing fire initiation plus the degree of success in controlling the impact of those fires that are initiated. This gate is a mutually exclusive "OR" gate. In any specific instant, success may be achieved by preventing fire or controlling it, but not by both.

2.1 Prevention of a Fire Initiation

Fire initiation is the start of the destructive endangering process of burning. The actual onset of fire initiation may be defined differently by different users of the tree. It is considered legitimate to define fire initiation by any of the critical events listed in Chapter 13 as a transition from State 0 to another state. It is essential, however, that the user of the tree declare his working definition of the onset of fire initiation and that this definition be held constant throughout that use of the tree.

Gate 2.1 - The degree of success in prevention of fire initiation is the sum of the degree to which all potential fuel is managed to keep it in an unignitable condition and the degree to which ignition sources are kept from any fuel that is in an ignitable condition.

3.1 Manage Fuel Ignitability

To be ignitable, a material must be combustible (i.e., a fuel) and be in a condition where the presence of ignition energy in contact with the fuel or volatilized effluent from the fuel bed will result in fire initiation.

Gate 3.1 - The degree of success in managing fuel ignitability is the sum of the degree that fuel is made unavailable to potential ignition energy sources plus the degree to which that available is prevented from reaching a susceptible condition.

4.1 Control Fuel Availability

A material is considered an available fuel if it is combustible and its location and character are such that it may exist in, or be brought to an ignitable condition by either normal or emergency environments.

Control fuel availability is the top event of a separate branch. This branch is covered in Chapter 4.

4.2 Control Fuel Susceptibility

To be susceptible a fuel must be available. An available fuel is susceptible to ignition if the inherent or situation induced conditions bring the fuel to a state where the presence of an ignition source can cause the onset of fire. Since ignition susceptibility applies only to those fuels that are available, all considerations of degree of success in this event are conditional on the degree of failure of Event 4.1, Control Fuel Availability.

Control fuel susceptibility is the top event in the branch of the tree covered in Chapter 5.

3.2 Limit Igniters

An igniter is any energy source sufficient to raise the temperature of an ignitable fuel (see Event 3.1) to the transition from a non-burning state to fire initiation (in accordance with the definition of fire initiation used in the particular application of the tree).

Limit Igniters is a conditional event. Success in this event contributes to the overall success of the tree only to the extent that such igniters relate to fuels that are in an ignitable condition (i.e., degree of failure of Event 3.1, Manage Fuel Ignitability).

Limit Igniters is the top event of the branch of the tree covered in Chapter 6.

12.1 Control Impact

Control impact is the top event in one of the two major subdivisions on the tree. (Prevention of Fire Initiation is the other major subdivision.)

All aspects of the tree relating to any state of burning, except State 0, Non-Burning (see Chapter 13), are covered under this event.

Impact is the extent and degree of harm that results if fire is initiated. Harm is measured in the same terms as the harm element of Event 1.0, Fire Safety Performance. Control impact is a conditional event dependent on the failure of Event 2.1, Prevention of Fire Initiation.

Gate 12.1 - The degree of success in controlling the impact of any fire that occurs is the sum of the degree that the fire threat is controlled plus the degree that the exposed (persons, property, or functional capability) are protected against the residual (uncontrolled amount of) threat.

13.1 Threat Control

Threat is the potentially harmful effects of fire as measured at any given place or moment in the fire. Threat is the combined harmful potential of all forms of change that are induced by fire, its effects, or the impact of fire control measures. Included are the combustion zone itself, smoke and heated or toxic gases, reduction in oxygen, structural collapses and extinguishment byproducts.

Gate 13.1 - The degree of success in threat control is the degree of concurrent control of the threat produced by the fire energy, the threat imposed by the mass products produced by the fire by itself or in combination with extinguishing efforts, and the threat from other fire induced conditions such as, oxygen depletion or roof collapse.

14.1 Control Threat Produced by Fire Energy

The fire energy threat is the fire (combustion reaction) itself and all forms of threat produced by that combustion and fire caused responses to it.

The degree of success in controlling the threat produced by fire energy is the sum of the degree of success in limiting the inherent potentials (size and level of energy) plus the degree of success of intervention efforts to stop or limit the development of that potential.

15.1 Limit Inherent Potential

The inherent potential of a fire is defined as the extent of spread of the combustion process and the resultant energy release, given the lack of successful intervention efforts to halt, limit, or terminate such potential.

Limit Inherent Potential is the top event of the branch covered in Chapter 7.

15.2 Control by Intervention

Intervention is the application of any fixed or "time-of-fire" feature or act that causes a termination, slowing, or other reduction in the potential fire energy threat. Intervention impacts on the outcome only to the degree that it reduces a threat that is not limited or controlled by the Limit Inherent Potential Branch.

Intervention is the top event in the branch of the tree covered in Chapter 8.

14.2 Control Mass Products Threat

Mass products are defined as the various chemical species and particulate products generated by the combustion process or by efforts to extinguish or control that process. Mass products also include any air or other gases entrained into the flow of fire generated products. Mass products include, but are not limited to, those fire products usually referred to as smoke and toxic gases.

Control Mass Products Threat is the top event in the branch of the tree covered in Chapter 9.

14.3 Control Other Fire Induced Threats

Other Fire Induced Threats is an open-ended term covering both the identified and potential, yet unidentified threats not covered under the definitions of Fire Energy or Mass Products. This includes but is not limited to the threats resulting from fire induced depletion of oxygen, roof or structural collapse, and pressure fronts produced by a fire induced explosion.

Control of Other Fire Induced Threats is the top event in the branch of the tree covered in Chapter 10.

23.1 Protect "Exposed"

Exposed is defined as the persons, property, or capabilities under consideration. Any specific definition is appropriate but it must be identical to that which is the objective of Event 1.0, Fire Safety Performance.

Gate 23.1 - The degree of success in protecting the "exposed" is the sum of the degree of success in limiting the quantity of "exposed" plus the degree to which the number of exposed persons or amount of property, or capacity present is safeguarded from the degree of threat not controlled by the events covered under Event 13.1, Threat Control.

24.1 Limit or Exclude "Exposed"

The definition of "Exposed" is as stated in Event 23.1, Protect "Exposed".

Limit or Exclude "Exposed" is the top event in the branch of the tree covered in Chapter 11.

24.2 Safeguard "Exposed" from Given Threat

The definition of "Exposed" is as stated in Event 23.1, Protect "Exposed". The degree of "exposed" consists of that which is not excluded or limited by Event 24.1, Limit or Exclude "Exposed". The threat of concern is the residual resulting from the degree of failure of Event 13.1, Threat Control.

Safeguard "Exposed" from Given Threat is the top event in the branch of the tree covered in Chapter 12.

CHAPTER 4. - CONTROL FUEL AVAILABILITY BRANCH (Figure 2)

4.1 Control Fuel Availability

A material is an available fuel if it is combustible and its location and character are such that it may exist in or be brought to an ignitable condition by either normal or emergency environments.

Gate 4.1 - The degree of success in controlling fuel availability is the degree to which fuels can be kept from the mine, plus the degree that fuel in the mine is removed, or is kept in a state or condition that makes it more difficult for environmental conditions to bring it to an ignition susceptible state.

5.1 Control Entry

Entry of fuel applies to any combustible material brought into the mine for construction, maintenance, comfort, production, or other reasons. The degree of success is the degree that such fuel is limited either by prohibition or control of the combustibility of the materials actually used.

This is an End Event in the event logic tree as drawn. The user of the tree may desire, at his own discretion, to extend this or any other End Event further into its constituent element if his needs so dictate.

5.2 Remove

Removal of fuel covers any action that takes the fuel (gas, liquid, or solid) from the mine.

Gate 5.2 - The degree of success of removal of fuel is the degree that fuel is taken from the mine by any means that transports it out of the environment.

6.1 Exhaust

Removal of fuel by exhaust is the removal of gases or airborne fuels from the excavate portions of the mine by exhaust fan or other pressure induced differentials.

6.2 De-gas

De-gasing is the removal of methane or other entrapped gases from the indigenous unmined coal mass prior to mining or excavation operations.

6.3 Clean

Removal by cleaning is the transport of solid or liquid materials that are no longer performing operational or other functions out of the mine. This includes both materials brought into the mines and the clean-up of any spillage of product coal that occurs from the mine production, haulage or storage of coal.

6.4 Other

Other is recognition that there can be removal arrangements other than those defined under Exhaust, De-gas, and Clean.

Events 6.1, 6.2, 6.3, and 6.4 are End Events in the Event Logic Tree as drawn.

5.3 Control of Availability of Fuel Present

The fuel present is all of that indigenous and non-indigenous fuel that is present in the mine at any instance. It includes both the mined and unmined coal; entrapped or liberated methane or other material; and all construction, operational, or other fuels that have been brought into the mine. Availability is the sum of the physical factors (e.g., particle size, location, encasements) that determine the degree of exposure of the fuel to the energy environment.

Gate 5.3 - The degree of success in Control of Availability of Fuel Present is the sum of the degree of success in preventing or limiting increases in factors that make fuel more available plus the degree to which fuels can be made less available to influence by energy environments.

6.5 Limit Increases in Availability of the Fuel

Increases in availability are those actions or processes that cause a fuel to become more available to influence by energy environments. The energy environments include all conditions (normal and abnormal) that bring radiated, convected, or conducted energy to a fuel. The source of the energy may be from any heat producing condition. Typical examples of design or controllable activities that influence any increase in the level of availability include:

A. The rate and mode of production at the working face(s).

B. The type and rate of product haulage including haulage system design elements that influence the amount of spillage or dust produced.

C. The condition of hydraulic systems in terms of the potential of spray or other release of combustible fluids from the contained system.

This is an End Event in the Event Logic Tree as drawn.

6.6 Reduction of the Availability of a Fuel (i.e., Control Fuel Exposure)

The reduction of the availability of a fuel is any act or arrangement that causes that fuel to be less exposed to influence by those energy environments that can result in ignition. Most typically this involves either the containment or covering of a fuel to barricade it from the fire inducing environmental conditions. Typical examples include:

A. Use of safety cans or other suitable containers for flammable liquids.

B. Sprayed concrete or other coating of the ribs or coal roof in portions of a mine.

This is an End Event in the Event Logic Tree as drawn.

CHAPTER 5 - CONTROL FUEL SUSCEPTIBILITY BRANCH (Figure 3)

4.2 Control Fuel Susceptibility

To be susceptible a fuel must be available. An available fuel is susceptible to ignition if the inherent or situation induced conditions cause a fuel to be in a state where the presence or an ignition source can cause the onset of fire. Since ignition susceptibility applies only to those fuels that are available, all considerations of degree of success in this event are conditional on the degree of failure of Event 4.1, Control Fuel Availability.

Gate 4.2 - The degree of success in controlling fuel susceptibility is the sum of the degree of success in maintaining environmental conditions outside the combustible limits of the fuel plus the degree of success in controlling the response to incident energy of those fuels in environments potentially within the combustible limits of the fuel involved.

5.4 Maintain Environment Outside Combustible Limits of Fuel

A fuel is outside of the combustion limits of that fuel if the ratio of fuel to oxidizer (air or oxygen) is such that combustion will not take place. For gases, aerosols, or dusts this applies to the mixture of any of these in the air. To solid materials such as piles of coal or gob this applies to the interface between the solid material and the surrounding environment.

Gate 5.4 - The degree of success in maintaining environments outside the combustion limits of the fuel is the sum of degree of success in maintaining environments that are fuel rich plus the degree of success in maintaining environments that are fuel lean.

6.7 Develop Fuel Rich Environment

A fuel rich environment is one in which either the concentration of fuel or the shortage of air or other oxidizers is such that combustion cannot take place.

Typical applications of this approach include:

A. The exclusion or removal of oxygen by the use of an inert gas or other inert material (rock dust, etc.) to encase or surround a condition (such as welding) where high temperatures and fuels might necessarily be in intimate proximity to each other.

B. The reduction of oxygen through absorption into the environment as occurs when gob or other abandoned areas are sealed.

C. The prevention of the mechanical dispersion of a combustible material from vibration and from high pressure (spray) leaks from hydraulic systems and as the secondary result of a methane ignition.

This is an End Event in the Event Logic Tree as drawn.

6.8 Develop Fuel Lean Environment

A fuel lean environment is one in which the amount of fuel is insufficient to undergo the combustion process. The typical example of a fuel lean environment exists in the properly designed mine exhaust stream that maintains methane below its explosive limits.

This is an End Event in the Event Logic Tree as drawn.

5.5 Control Temperature Dependent Susceptibility

Temperature dependent susceptibility factors are those that control the level of temperature at which a fuel (not maintained outside of combustible limits

by Event 5.4) volatilizes sufficiently to produce a combustible mixture susceptible to ignition.

Gate 5.5 - The degree of success in controlling the temperature dependent factors is a multi-variant relationship between the level of control of the critical volatilization temperature of the fuel and the degree of control of the temperature rise in the fuel.

6.9 Manage Critical Temperature of Fuel

The critical temperature of a fuel is that surface temperature at which the rate of volatilization of combustible matter is such that the entry of an ignition energy can initiate fire as defined in Event 2.1, Prevention of Fire Initiation. This is normally accomplished by techniques such as:

A. Use of noncombustible material (infinitely high critical temperatures).

B. Selection of materials that inherently have higher critical temperatures.

C. Treatment of material to increase the critical temperature of a material.

This is an End Event in the Event Logic Tree as drawn.

6.10 Maintain Surface Temperature Below Critical Level

Given the degree of control of critical temperature, the susceptibility of a fuel is determined by the degree to which such fuel can be maintained below that critical temperature. For each fuel there is potentially a different critical surface temperature. Some fuels have critical temperatures below ambient temperatures. For flammable liquids the critical temperature is traditionally described in terms of flash point.

Gate 6.10 - The degree of success in maintaining surface temperatures below the critical level is the degree to which there is concurrent success in cooling any materials that have critical temperatures at or below ambient temperature to a level lower than their critical temperature, and the degree of success in preventing critical temperature rises in those materials that have critical temperatures higher than ambient temperature.

7.1 Reduce Surface Temperature of Fuel Below Critical Temperature

Reduction of surface temperature below the critical temperature includes any action or arrangement that either reduces the surface temperature directly as by surface cooling or which reduces the overall ambient environment below that which is critical (e.g., ventilation cooling of a space to prevent self-heating)

This is an End Event in the Event Logic Tree as drawn.

7.2 Prevent Temperature Rise of Fuel

For those fuels where the critical temperature is above ambient, susceptibility to ignition can be controlled by preventing rise in the surface temperature of such material.

Gate 7.2 - The degree of success in preventing the surface temperature rise is the sum of degree of success in preventing the impact of incident energy upon the fuel, plus the degree of control of response of that fuel to incident energy.

8.1 Interpose Energy Transfer Barrier Between Energy Source and Fuel

Barriers may be total or partially effective in preventing the transfer of heat energy, depending on their position and energy response. Such barriers, may be on the heat source, on the target, or at some intervening point between.

This is an End Event in the Event Logic Tree as drawn.

8.2 Control Response to Incident Energy

The characteristic response to incident energy can be controlled or predicted in terms of the characteristics of the incident energy source and the responding characteristics of the fuel.

Gate 8.2 - The degree of success in controlling the response to incident energy is a multi-variant relationship between the incident energy and the resistance to incident energy impact of the individual item.

9.1 Incident Energy

Incident energy is that energy which reaches the fuel surface from all energy producing sources.

This is an End Event in the Event Logic Tree as drawn, however, Functional Branch A outlines the basic physical elements that determine the level of incident energy.

Functional Branch A - Incident Energy (Figure 11)

The incident energy impact on a target fuel is the sum of the energy radiated to that target plus the energy conducted to that target plus the energy convected to that target.

A-1 Radiation - Radiation is the transfer of heat from one body to another by means of wave motion through space. The amount of energy radiated at the target is a function of the absolute temperature of the radiator (A-4), the emissivity (i.e., radiant efficiency) (A-5), and the configuration or viewing factor relationship between the fire source and the target (A-6). The amount of radiation varies with the fourth power of the absolute temperature and directly with emissivity and configuration factor. The emissivity or radiation efficiency of many

solid materials varies with the temperature of that material. Configuration factor is a spherical geometry relationship that depends upon the size of the radiation source (length and width), the distance between the radiation source and the target, and the angle between the face of the radiator and the line site to the target.

A-2 Conducted Energy - Conduction is the transfer of heat from one part of a body to another part of the same body or from one body to another in physical contact with it.

A. Conduction through a body (A-7) is a function of the temperature differential between the exposed and the unexposed faces of the heat conducting body (A-8), the thickness of the conducting body (A-9), the thermal inertia (KpC) of the conducting body (A-10) and the thermal conductivity (K) of the conducting body (A-11).

B. Conduction between physically contacting bodies (A-12) is a function of the temperature differential between the bodies (A-13) and the effective heat transfer coefficient involved (A-14).

A-3 Convected Energy - Convection is the transfer of heat from one point to another within a fluid (gas or liquid) by movement of heated portions of the fluid or by the mixing of one portion of the fluid with another. The convected energy is a function of the temperature differential and mass of the heated portion of the fluid (A-15), the relative position of the source of the heated gas and the target (A-16), and the cooling of the gases in transit (A-17). The cooling of the gases in transit are in turn a function of any energy lost from the gases through radiation (A-18) through conduction to other portions of the fluid mass through dilution and mixing (A-19) and the conduction of energy due to contact between the fluid and any other body (surface) (A-20).

9.2 Resistance to Energy Impact

The resistance to energy impact is the characteristic response of a material to the impact of incident energy on it. This response is in terms of the speed at which surface conditions progress toward equilibrium with the incident energy. The slower the surface temperature rise the more resistance to energy impact.

This is an End Event in the Event Logic Tree, however, Functional Branch B outlines the basic physical elements that control the response of a material to incident energy.

Functional Branch B - Resistance to Energy Impact (Figure 11)

The resistance to energy impact is a combined function of the thickness of the material (B-1), the reflectivity of its surface (B-2), and its thermal inertia (B-3). Thermal inertia is a measurement of the capability of the target material to receive heat energy and absorb or distribute it within. Thermal inertia is a function of the thermal conductivity (B-4), the density (B-5), and the specific heat (B-6) of the material. Some of these factors vary through the course of exposure with temperature change. The target surfaces of low thermal inertia materials quickly come to equilibrium with incident energy (heat up quickly). Conversely, the target surfaces of high thermal inertia materials tend to resist coming to equilibrium by dissipating the energy through the mass of the material. As materials become thicker, relative importance of thickness decreases. For very thin materials (cloth, thin plywood, coal dust, etc.) thickness is a critical element. For thicker materials such as heavy timbers or the undisturbed coal mass, the thickness is infinite as far as thermal energy transfer is concerned.

CHAPTER 6 - LIMIT IGNITERS BRANCH (Figure 4)

3.2 Limit Igniters

An igniter is any energy source sufficient to raise the temperature of an ignitable fuel (see Event 3.1) to the transition from a non-burning state to fire initiation in accordance with the definition of fire initiation used in the particular application of the tree.

Gate 3.2 - The degree of success in limiting igniters is the degree to which there is concurrent control of both pilot ignition sources and self (auto) ignition potentials. The contribution of the degree of success in limiting igniter to the overall Event Logic Tree success is conditional on the degree of failure of Event 3.1 (i.e., limiting the availability of ignition susceptible fuels). By definition, the simultaneous failure of both Event 3.1 and 3.2 (i.e., the joining of a susceptible, ignitable fuel and an igniter) is failure of Event 2.1, Prevention of Fire Initiation.

4.3 Control "Pilot" Ignition Potential

Ignition pilots are energy sources external to the potential fuel that can start the combustion reaction necessary for fire initiation as specified by Event 2.1, Prevention of Fire Initiation, when exposed to a fuel in an ignitable condition as defined by Event 3.1.

Gate 4.3 - The degree of success controlling pilot ignition potential is the sum of the degree to which pilot ignition sources are excluded from areas of fuel ignitability plus the degree to which those sources that are not excluded are otherwise controlled to prevent the imposition of ignition level energy on the ignitable fuels.

5.6 Prohibit, Limit, Exclude

The objective of this event is to prevent the intersection of a pilot ignition source with an ignitable fuel. The extensive degree of ignitable fuel and the

frequency and variety of pilot ignition sources inherent in coal mines tends to limit the extent of success of this event. However, the degree that pilot ignition sources such as open flames, arcing equipment, and hot bodies can be kept out of the mine, add to the success of this event. Success is also achieved in cases where the location of pilot ignition source, such as welding equipment, is controlled to separate it from ignitable fuels.

This is an End Event in the Event Logic Tree as drawn.

5.7 Other Protection

Other protection includes any devices or arrangements that preclude a potential pilot ignition source from causing ignition including: reduction of the level of energy of a device below that necessary to cause ignition of the susceptible fuel; inherently safe electrical equipment; equipment so designed that if a combustible mixture reaches the point where the energy level is sufficient for ignition potential, propagation will take place (e.g., explosion proof equipment and the flame arrestors in methane detection lamps); or other pilot igniter protection arrangements.

This is an End Event in the Event Logic Tree as drawn.

4.4 Control Self (auto) Ignition Potential

Auto ignition is defined as ignition that occurs in the absence of pilot igniters. In this case ignition results from raising the temperature of the fuel itself to the point where its own surface temperature exceeds the energy level necessary to ignite it or the material volatilized from it.

Gate 4.4 - The degree of success in controlling auto ignition as a contribution to the overall degree of success in limiting igniters is that degree to which auto ignition is prevented when there are no pilot igniters (i.e., when Event 4.3 is also successful). Within this constraint, the degree of success is the degree of success in concurrently preventing both internally induced (self) heating and externally induced heating.

5.8 Internally Induced Heating Control

Internally induced heating is defined as that heating in which the temperature of the heated material is higher than the surrounding ambient atmosphere. Such heating is normally a function of the inherent self heating characteristics of the material (e.g., coal and its entrained volatile products); the total mass, the amount of radiant surface to dissipate heat (in terms of a surface to mass ratio), the temperature of the mass, and the temperature of the surrounding environment.

This is an End Event in the Event Logic Tree as drawn.

5.9 Externally Induced Heating Control

Externally induced heating is defined as heating of a mass from an external environment or a heat source in the external environment at a higher temperature than target fuel. The factors controlling this event are identical to those controlling the development of Event 5.5, except that the critical temperature of concern is critical ignition temperature rather than critical volatilization temperature.

This is an End Event in the Event Logic Tree as drawn.

CHAPTER 7 - LIMIT INHERENT POTENTIAL BRANCH (Figure 5)

This branch of the tree relates to the inherent or unencumbered energy production potential of an ignited fuel. It does not treat those actions or arrangements such as suppression or confinement that can mitigate this potential, nor does it treat the resulting threat that can occur from smoke gases and other mass products produced, or separate threats such as oxygen depletion or mine collapse. Each of these are covered in separate chapters.

15.1 Limit Inherent Potential

The inherent potential of a fire is defined as the extent of spread of the combustion process and the resultant energy release if there are no successful installed or emergency instituted devices or efforts to halt, limit, or terminate it.

Gate 15.1 - The degree of success in limiting the energy potential is the degree of success in concurrent control of the extent of the burning area, the energy characteristics of the burning area, and the duration of burning.

16.1 Control Extent of Burning Area

The extent of burning area is defined as the surface area of all materials undergoing destructive oxidation at any time plus all portions of the flame body that are undergoing energy generating combustion reactions.

Gate 16.1 - The degree of success in controlling the extent of the burning area is the degree to which there is concurrent control of both the extent of flame spread across combustible surfaces and the control of the involvement of additional fuels through other means.

17.1 Control Surface Flame Spread

Surface flame spread is defined as the progressive involvement across the surface of a continuous or nearly continuous combustible face from a fire source emitting from or in intimate contact with the surface.

Gate 17.1 - The degree of success in controlling the surface flame spread is the sum of the degree of success that the response of the materials involved can be controlled to obstruct or retard flame spread plus the degree to which the external environmental factors can be controlled to prevent energy reinforcement of flame spread.

18.1 Control Material

Control of a material relates to both the inherent flame spread characteristics of the material and the response of that material to incident energy from its own flame or from other sources.

Gate 18.1 - The degree of success in controlling surface flame spread through control of materials is the sum of the degree that the chemical burning characteristics of the material are controlled and the degree to which the thermal response of a material is controlled.

19.1 Control Chemical Response

Chemical response is the subjectivity to pyrolysis of the constituent molecules volatilized from the base material or reacted in place in the material matrix. Methods of controlling this process include the use of materials that are either non-combustible or inherently have low combustibility (e.g., use of masonry block or transite material to construct shop partitions or the clearing of the overhead to bare rock to eliminate the combustibility of the ceiling). Alternatively chemical control of the response of an inherently combustible material can be enhanced by fire retardant treatment (e.g., fire retardant treated wood or fire retardant treated brattice).

This is an End Event in the Event Logic Tree as drawn.

19.2 Control Temperature Rise of Unignited Portions of Surface

The unignited portions of the surface must be raised to a temperature sufficient to evolve an ignitable concentration of volatilized combustion products from the uninvolved surface in front of the flame front. The energy to do this may come from the advancing fire on the adjacent surfaces or from any other source.

Gate 19.2 - The degree of success in controlling the temperature rise of unignited portions of a surface is the sum of the degree of success in interposing barriers to energy transfer between the energy source and the unignited portion of the surface plus the degree of success in controlling the response of the surface to the incident energy that strikes it.

20.1 Obstruct Energy Transfer to Surface

The energy transfer to the surface of a combustible material is limited to that energy that actually reaches and is transferred to that material.

Gate 20.1 - The degree of success in obstructing energy transfer is a multivariant functional relationship between the energy exposure and the effectiveness of the obstruction to the transfer of such exposure to the unignited surfaces.

21.1 Energy Exposure

Energy exposure includes all forms of energy that are present in a form and level that has a potential of impacting on a target material.

This is an End Event in the Event Logic Tree as drawn, however, Functional Branch A, as described in Chapter 5, covers the factors that control the level of energy exposure and the potential incident energy where no obstructions are present.

21.2 Effectiveness of Obstructions to Energy Exposure

Obstructions to energy exposure include any type of barrier or energy absorbing media between the energy producing source and the target surface; insulation or barriers applied to the target; and cooling systems (e.g., water sprays) that remove energy reaching the target before it can be transferred to the target surface.

This is the End Event in the Event Logic Tree as drawn.

20.2 Control Response to Incident Energy

The response of the material to incident energy (relative to surface flame spread) is the potential of the surface zone of that material to rise in temperature given the degree of energy impact of the surface (i.e., degree of failure of Event 20.1).

Gate 20.2 - The control of response to incident energy is a multi-linear function of the relationship between the incident energy actually impacting on the target surface and the resistance of that surface to such energy impact.

21.3 Incident Energy

The incident energy striking the surface zone is all of the energy not obstructed in accordance with Gate 20.1.

This is an End Event in the Event Logic Tree as drawn.

21.4 Resistance to Energy Impact

The resistance to energy impact is the capability of the target surface to receive incident energy and distribute it within or through the target material in such a manner as to retard the tendency of that material to rise in surface temperature towards equilibrium with the incident energy.

This is an End Event in the Event Logic Tree as drawn, however, the functional elements controlling the resistance to energy impact are those described in Functional Branch B previously discussed under Chapter 5.

18.2 Control Level of Energy Exposure to Unignited Portions of Surface

Event 18.1 governs the response of a surface to an exposing energy environment relative to fire initiation. This event is designed to govern the response of

a surface to an exposing energy environment that occurs after fire initiation. In all other aspects, the two events are identical.

Gate 18.2 - The degree of success in controlling the energy exposure is the degree that there is concurrent control of the total energy developed by the exposure produced by the involved portions of the surface along with control of any other exposure produced from other aspects of the general environment.

19.3 Control Exposure from Involved Portions

The transfer of energy from the involved (burning) portions is primarily from the flame and radiative in nature. In some cases, conductive energy may be a factor. This is most likely in the slow propagation characteristic of smoldering fires.

This is an End Event in the Event Logic Tree as drawn.

19.4 Control Exposure from General Environment

In addition to the energy directly from the flame, the rate of propagation of fire across a combustible surface is also strongly influenced by any supportive incident radiation coming from any other source. This is important when energy levels in the environment reach levels that impose incident energy on portions of the surface at levels higher than the energy transfer from its own burning flame (Event 19.3). The factors controlling this event are the same as those involved in Event 16.2, Control Fire Intensity.

This is an End Event in the Event Logic Tree as drawn.

17.2 Control Other Means of Extension of Burning Area

In addition to the degree of fire extension resulting from the degree of failure to control surface flame spread, other forms of fire extension can occur involving materials that are either separated from the continuous

burning surface, or if part of such surface, are sufficiently removed from the involved area that they are not part of the flame spread phenomena.

Gate 17.2 - The degree of success in preventing other means of extending the burning area is the degree of success in concurrently preventing fire induced ignition of other fuels along with controlling environment induced involvement (flashover and other ventilation control conditions).

18.3 Prevent Fire Induced Ignition of Other Fuels

Fire induced ignition of materials is classified as successive ignitions following the same functional controls as the prevention of fire initiation. For this reason, the guidance in the tree refers the user to Event 2.1. The conditions covered in 2.1 are then repeated at the higher level of energy in the exposing fuel.

This is an End Event in the Event Logic Tree as drawn.

18.4 Control Exposure from General Environment

The energy exposure resulting from the increase in environmental energy conditions can induce flashover or other means of propagation without the direct transfer of energy from the flame or flame plumes of the burning material. The factors controlling this event are the same as those involved in Event 16.2, Control Fire Intensity.

This is an End Event in the Event Logic Tree as drawn.

16.2 Control Fire Intensity

The fire intensity is defined as the position and level of the fire induced energy emitting bodies (solid, liquid, or gas) in the environment. Normally this is defined in terms of temperature distribution and appropriate efficiency factors such as emissivity, specific heat, or other factors relative to heat transfer.

This is an End Event in the Event Logic Tree as drawn, however, Functional Branch C outlines the elements that are the parametric variables controlling the energy characteristics of a given environment.

Functional Branch C - Fire Intensity (Figure 12)

The overall energy characteristics of an environment are the combined function of the rate of energy production, both at any instant, and the history of that production through the course of the fire (C-1); the energy losses, both at any instant, and the history of energy losses through the course of the fire (C-2); and the physical arrangement of the environment (C-3).

The energy production rate is in turn a function of the incident energy (C-4), the response of materials to incident energy (C-5) (as outlined in Functional Branch B), the volatilization rate of the materials as a function of the surface temperature (C-6), and the energy produced per unit mass volatilized (C-7).

The energy produced per unit mass volatilized is a function of the inherent chemical makeup and properties of the materials involved (C-8), and the availability of the air necessary for the combustion process (C-9).

The air for combustion is controlled by the mass available (a function of the physical environment) (C-10), the entrainment of the air into the fire plume (C-11), and the oxygen content of the air (C-12).

Energy losses include those that are vented (i.e., convected from the fire scene) (C-13), those that are radiated from the fire plume (C-14), and those that are transferred to the environment by conduction (C-15).

The influencing physical arrangement of the environment includes all factors of geometry such as height, volume, plan dimensions, and slope. In addition, important environmental considerations relate to the ventilation means by

which the fire can obtain the necessary air, and any means available to vent combustion products.

16.3 Control Fire Severity

Fire severity is defined as the total high temperature energy imposed by the fire through its duration or up to point of interest. It is frequently measured in terms of a cumulative time versus temperature curve or occasionally as rate of energy transfer versus time.

Gate 16.3 - The degree of success in controlling severity is the sum of the degree of success in controlling fire intensity and the degree of success in limiting the duration of such intensity through limitation of the total available fuel mass for combustion.

17.3 Control Fire Intensity

Event 17.3 is identical to Event 16.2.

This is an End Event in the Event Logic Tree as drawn.

17.4 Limit Available Fuel Mass

The available fuel mass is defined as all materials that are both capable of releasing energy under fire exposure and subjected to oxidation reaction, given the degree of failure to control fire intensity. This is normally measurement of the mass of such material.

This is an End Event in the Event Logic Tree as drawn.

CHAPTER 8 - CONTROL BY INTERVENTION BRANCH (Figure 6)

15.2 Control by Intervention

Intervention is the application of any fixed or time-of-fire feature or act that causes a termination, slowing, or other reduction in the otherwise potential fire energy threat. Intervention impacts on the outcome only to the degree that it reduces a threat that is not limited or controlled by the features under the Limit Inherent Potential Branch (Chapter 7).

Gate 15.2 - The degree of success of control by intervention is the sum of the degree of success of control by suppression or other forms of termination plus the degree of success of control by confinement.

16.4 Control by Suppression of Burning

Suppression is any action that stops or reduces the extent, intensity, or severity of fire below the inherent potential residual from the degree of failure of Event 15.1.

Gate 16.4 - The degree of success in control by suppression is the sum of the degrees of success of the collective impact of control by removal of fuel availability, cooling or quenching, oxygen deprivation, or other means.

17.5 Control by Removal of Fuel Availability

The removal of fuel availability is any action that extracts fuel from any area where it can become involved as a result of the conditions outlined under Event 15.1. Typical actions include the physical removal of an exposed fuel from the threat of an advancing fire (removal of coal in a pile or bunker) or the covering of a threatened fuel with a barrier to make it inaccessible.

This is an End Event in the Event Logic Tree as drawn.

17.7 Control by Cooling

Cooling is any action that removes heat from the fire bed or the produced hot gases or heated surface. It also includes forms of cooling that increase the difficulty of ignition of unignited materials (primarily by wetting). For the most part, the cooling media is water that may be manually or automatically applied in a traditional form of water or as high expansion foam. A common set of functional criteria apply to all such systems. These criteria are outlined in Functional Branch D.

This is an End Event in the Event Logic Tree as drawn, however, Functional Branch D provides interrelationships of the parameters that control the degree of success of a suppression system.

Functional Branch D - Suppression System (Figure 13)

The capability of a suppression system (manual or automatic) is a function of its availability relative to the area of suppression needs (D-1), its ability to recognize and respond to the need (D-2), and its suppression capability when applied (D-3).

Availability is defined as the proximity of the sensing and activation devices to the fire of a fixed system and the proximity and availability of a safe access path for persons and equipment in cases of manually operated systems.

Response is a combined function of the sensitivity of the responding mechanism (D-4) and its initiation reliability (D-13). Initiation reliability (D-13) in the case of automatic equipment is reliability, in terms of sensing the fires signature and of activating all elements necessary to deliver the suppression agent.

Sensitivity (D-4) is the response ability of the initiating device (or persons) to the fire situation created by the level of fire characteristics resulting from the degree of failure of Event 15.1.

Sensitivity is a multi-variant function of the signature production and transmission (D-5) and the detector response to it (D-9). In such case, the signature production of interest is that to which the detector can respond.

Signature production and transmission (D-5) is in turn a function of the actual energy signature production of the fire (D-6), the relative position of this production to the detector location and the level of energy in the detectable signature media (D-7), and the space geometry involved (D-8).

Detector response (D-9) is a function of the resistance of the detector to signature admission or accumulation in the actual detection zone (D-10), the signature level required to activate the detector (D-11), and any internal system time constants or delays (D-12). In the case of fixed systems, these internal time constraints are normally mechanical or electronic. In the case of human detectors, they may be administrative.

Suppression (D-3) is the concurrent capability of the suppression system once it has responded (D-14), and the trans-fire reliability in terms of the ability of the system to stay in proper operating order under the ensuing fire exposure for a sufficient period of time to fulfill its function (D-17). Suppression capability is a mass density function relationship between the extent of burning area and intensity of the fire (degree of failure of Event 16.1 and 16.2) (D-15) relative to the agent's capability as applied against the given levels and extent of burning (D-16).

17.6 Control by Oxygen Deprivation

Oxygen deprivation is any activity which prevents oxygen from reaching the fire.

Gate 17.6 - The degree of success in control of fire through oxygen deprivation is the sum of the degree of control obtained by replacing oxygen with inert gas or by exclusion of oxygen by other means.

18.5 Replace Oxygen with Inert Gas

Inert gases include both inert gases especially designed or generated for the purpose of fire control such as carbon dioxide or nitrogen and the inert products of combustion produced by a fire itself.

This is an End Event in the Event Logic Tree as designed, however, the parameters described in Functional Branch D also apply to inert gas systems.

18.6 Exclude Oxygen by Other Means

Other means include any non-gas approach. Such are likely to involve covering the burning material with a solid material such as rock dust or blocking oxygen entry by sealing or other means to prevent the fire from drawing fresh air.

This is an End Event in the Event Logic Tree, however, the performance of systems for exclusion of oxygen are also subject to the parametric element described in Functional Branch D.

17.8 Control by Other Means

All other means of suppressing fire are covered under this category. The principal envisioned mechanisms are those approaches that interfere with the chemical train of the combustion process such as fire extinguishment using halogenated agents.

This is an End Event in the Event Logic Tree, however, as with all other suppression systems the functional parameters in Functional Branch D apply.

16.5 Control by Confinement of Extent of Burning

Confinement of the extent of burning is defined as the establishment of a barrier or other perimeter that prevents the advance of the combustion process beyond some point.

Gate 16.5 - The degree of success of control by confinement is the degree of the concurrent success in maintaining the completeness of the perimeter, its structural endurance, and its thermal endurance.

17.9 Perimeter Completeness

Completeness is the degree to which the perimeter (normally defined by stopping or another barrier) is sufficiently continuous to prevent the passage of fire and flame or other hot gases sufficient to cause ignition on the unexposed side of the barrier. The degree of success in completeness is a measurement of the degree of prevention of ignition passage rather than a measurement of degree of totality of the perimeter.

Perimeter completeness is an End Event in the Event Logic Tree as drawn, however, Functional Branch E lays out the factors that determine the probability of success in terms of completeness.

Functional Branch E - Barrier Completeness (Figure 13)

The functional factors that determine the probability that ignition will pass through any openings in a barrier include the number, size and position of the openings (E-1), the exposing energy level and position as developed from the degree of failure in Events 16.1 and 16.2 (E-2), the location of the flame relative to barrier openings and the amount of excess pyrolysate in the flame body (E-3), and the relative position of external (exposed) fuel on the unexposed side of the barrier vis a vis the barrier openings (E-4). Failure is considered to be the transfer of ignition to a fuel on the unexposed side of the barrier.

17.10 Provide Structural Endurance

Structural endurance is the capability of a perimeter to hold its shape and position during the exposure presented by the imposed fire conditions. Where a barrier or other perimeter member depends upon other members (columns,

beams, etc.), the endurance of those members is an integral part of structural endurance.

Gate 17.10 - The degree of success in providing control through structural endurance is a multi-variant relationship between the fire's severity (the degree of failure of Event 16.3), and the structural endurance of the member.

18.7 Fire Severity

Fire severity is the degree of failure to control the severity as defined under Event 16.3.

This is an End Event in the Event Logic Tree as drawn.

18.8 Structural Endurance Capability

Structural endurance is the capability of a perimeter element and its supporting members as installed and protected at the time of fire to withstand and hold their shape, form, and load when subjected to fire.

This is an End Event in the Event Logic Tree, however, Functional Branch F points out the two essential considerations in functional parameters.

Functional Branch F - Endurance (Figure 13)

Endurance of a member exposed to fire is a combined function of the inherent endurance of that member (F-1) plus any endurance enhancement applied at the time of exposure (F-2). Endurance enhancement is most likely in the form of water spray or other means intended to reduce the impact of energy incident on the member.

17.11 Provide Thermal Endurance

Thermal endurance is the capability of a perimeter element to resist the conductive transfer of energy from the exposed to the unexposed side. The

measurement of the degree of success is the degree to which ignition through energy transfer is avoided.

Gate 17.11 - The degree of success in providing control through thermal endurance is a multi-variant relationship between fire severity and the thermal endurance response of the element.

18.9 Fire Severity

Fire severity is identical to the fire severity described under Event 18.7.

This is an End Event in the Event Logic Tree as drawn.

18.10 Thermal Endurance Capability

Thermal endurance capability is the ability of the perimeter system as installed to prevent the transfer of energy from the exposed to the unexposed side.

This is an End Event in the Event Logic Tree as drawn, however, Functional Branch F provides factors related to the development of endurance.

CHAPTER 9 - MASS PRODUCT THREAT BRANCH (Figure 7)

14.2 Control Mass Products Threat

Mass products are defined as the various chemical species and particulate products generated by the combustion process or by efforts to extinguish or control that process. Mass products also include any air or other gases entrained into the flow of fire generated products. Mass products include, but are not limited to, all of those fire products usually referred to as smoke and toxic gas.

Gate 14.2 - The degree of success in controlling mass product threat is the sum of the degree of success in controlling the production of such products plus the degree that the movement of those products produced is managed.

15.3 Control Product Production

Product, as used herein, is the conglomerate airborne material produced as byproducts of fire, airborne elements of extinguishing agents, and any products produced as a result of the application of such extinguishing agents in the fire environment.

Gate 15.3 - The degree of success in controlling product production is a multi-variant relationship between the fire energy threat (i.e., lack of control of such threat under Event 14.1) and the products produced given such threat.

16.6 Fire Energy Threat

Fire energy threat is the degree of failure of Event 14.1, that is, the extent and magnitude of fire threat that will potentially be available. The dimensions of measurement are in terms of rate of energy release with such additional factors as are pertinent to production of product gases. These factors include variables such as extent of flaming and sufficiency of oxygen.

This is an End Event in the Event Logic Tree as drawn.

16.7 Products Produced

The products defined by this event are those produced when the material is exposed to the fire energy threat defined in 16.6, including the impact of any intervention approach covered under Event 15.2.

This is an End Event in the Event Logic Tree as drawn.

15.4 Manage Product Movement

Product movement is the mass transfer of all or part of the products produced.

Gate 15.4 - The degree of success in managing product movement is the sum of the degree of success in controlling the movement energy that provides the dynamic head to the gas mass plus the degree to which this movement is controlled given the dynamic head.

16.8 Control Movement Energy

Movement energy is the pressure differential above the normal for the area. This pressure differential is the measurement of the energy forces capable of moving the gas body.

Gate 16.8 - The degree of success in controlling movement energy is the degree to which there is concurrent control of the fire induced energy and energy induced into the gas by other means.

17.12 Control Fire Induced Energy (Buoyancy)

Fire induced energy is that energy caused by the thermal expansion of the gas body due to the fire induced energy which remains in the gas body.

Gate 17.12 - The degree of success in control of fire induced buoyancy is the sum of the degree of success in reducing the gas body temperature by adding a cooling means to the gas mass plus the degree of success in cooling the gas body temperature by transfer of energy to other materials.

18.11 Control by Adding Cooling Agents

Cooling agents are any liquid or gas added to the gas mass that results in a lower temperature of the resulting mass. Most commonly this is either from dilution with cooler air or from a water spray, automatically or manually applied.

This is an End Event in the Event Logic Tree as drawn.

18.12 Control by Transfer to Other Masses

Heat transfer to other masses is defined as that heat conducted to masses such as the roof faces and ribs of the mine as a result of the contact of the hot gases with those bodies or similar transfer by radiation. Each of these transfers is a function of the temperature differential between the gas body and the energy receiving surface. In the case of radiant transfer, it is also a function of the emissivity (energy transmission efficiency) of the gas.

This is an End Event in the Event Logic Tree as drawn.

17.13 Control Other Gas Movement Forces

Other energies include any mechanism other than the entrained heat that causes a pressure differential resulting in gas movement. (Examples of sources of such energy would include fans, barometric pressure differentials, and wind.)

Gate 17.13 - The degree of success in controlling other gas movement energy is the degree of success in the concurrent control of each such potential energy.

18.13 Control Mechanically Induced Forces

Mechanically induced forces are those forces developed by a mechanical arrangement designed to move air or provide gas pressure differentials capable of moving the gas mass. Generally this is dominated by the mine ventilation system but also includes any casually produced forces such as might be induced by any piston action of a hoist or other mechanism.

This is an End Event in the Event Logic Tree as drawn.

18.14 Control Barometric Induced Forces (Stack Effect)

Barometrically induced forces or stack effect are those that result from the pressure differential caused by the difference in barometric pressure between two points in the mine system and is normally a function of the height of the shaft and the total barometric pressure resting at the base of the shaft versus the total barometric pressure in some other connected part of the system.

This is an End Event in the Event Logic Tree as drawn.

18.15 Control Wind Induced and Other Forces

Wind induced forces are those caused by natural winds that may either blow into the mine or across the face of an opening. "Other forces" is a catch-all statement to cover any other gas movement energy forces. No examples of such other forces are included.

This is an End Event in the Event Logic Tree as drawn.

16.9 Control Movement

The movement of a gas body is the transfer of a mass from one location to another. This event is conditional on the movement energy residual due to the degree of failure involved in Event 16.8.

Gate 16.9 - The degree of success in control of movement is the sum of degree of success in obstructing movement with barriers plus the sum of degree of success in managing the fluid dynamics of that not controlled by barriers.

17.14 Obstruct Movement with Barriers

Barriers include any obstacle to the flow of a gas body. In general, a barrier is not effective unless it encloses all or most of the potential gas movement opening. Most barriers have some degree of potential gas leakage,

depending on the pressure differential between the clean and smoke laden side of the barrier. The success of barriers is also dependent upon their success as a confinement media as covered in Event 16.5.

This is an End Event in the Event Logic Tree as drawn.

17.15 Manage Fluid Dynamics

The fluid dynamics of concern are the flow, movement, and concentration of species in the gas body. This is considered conditional on the degree of failure to obstruct the movement with barriers.

Gate 17.15 - The degree of success in managing fluid dynamics is the sum of the degree of success in controlling the gas mass concentration, by dilution; controlling the gas mass flow by exhaust or venting; and control of gas movement with pressure differentials.

18.16 Control by Dilution

Control of the gas mass by dilution consists of entering air into the gas mass to reduce the density of harmful products. Dilution in this event is the same dilution as covered under Event 18.11, but the function is different and the resulting degree of success for a unit mass of dilution will not be the same in these two events.

This is an End Event in the Event Logic Tree as drawn.

18.17 Control by Exhaust or Venting

Exhausting or venting in this context is any mechanism that removes the products from the mine using either the buoyant force of the hot gases itself or a fan induced arrangement which draws the undesirable gases to the venting fan.

This is an End Event in the Event Logic Tree as drawn.

18.18 Control with Pressure Differential

Control by pressure differential covers any approach where a force is created by fans or any other means that develop a head pressure on the clean area higher than the pressure imposed by the gas mass, thereby blocking its advance or forcing its retreat. Frequently pressure differential approaches are used in combination with barriers to control the degree of failure to obstruct gas flow inherent in the barrier. In coal mines, it is also possible to create pressure differentials in selected entry ways without special barriers at the interface.

This is an End Event in the Event Logic Tree as drawn.

CHAPTER 10 - OTHER FIRE INDUCED THREATS BRANCH (Figure 8)

14.3 Control Other Fire Induced Threats

"Other Fire Induced Threats" is an open ended definition covering both the identified and potentially yet unidentified threats not covered under the definition of fire energy threats or mass products threats. This includes, but is not limited to, the threats resulting from fire induced depletion of oxygen, roof or structural collapse, and shock waves as might be induced by a fire induced explosion.

Gate 14.3 - The degree of success in controlling other fire induced threats is the degree of concurrent control of fire induced depletion of oxygen, prevention of roof or structural collapse, control of shock waves, and control of other threats.

15.5 Control Oxygen Depletion

Oxygen depletion is the lowering of the oxygen fraction in a portion of the mine below that necessary for life support. Fires, fire induced conditions,

and efforts to attack fire may all result in depletion of the oxygen in the environment. It may occur in the fire product gas stream or in other areas.

This is an End Event in the Event Logic Tree as drawn.

15.6 Prevent Mine Collapse

Mine collapse is defined as the failure of any part of the mine roof or of any other element in a manner that poses a threat.

This is an End Event in the Event Logic Tree as drawn.

Prevent Hazardous Shock Waves or Other Threats

Ignition of combustible gases such as methane or carbon monoxide, or other environmental situations, can initiate a shock wave or pressure surge through the mine shaft posing threat to persons and property.

Other threats are expected to occur but have not been defined at this stage of development of the Event Logic Tree. The inclusion of "Other" in this gate is to maintain an open ended system permitting future analysis of any unidentified threats.

This is an End Event in the Event Logic Tree as drawn.

CHAPTER 11 - LIMIT OF EXCLUDE "EXPOSED" BRANCH (Figure 9)

24.1 Limit or Exclude "Exposed"

The term "exposed" is defined as those persons, property, or operational capability whose harm would be detrimental to the achievement of the fire safety objectives stated in Event 1.0. Exclusion is defined as prohibiting entry of the "exposed" into the mine. Limit is defined as allowing entry but restricting the total amount, or concentration of importance with the mine.

Gate 24.1 - The degree of success in achieving protection of the "exposed" by limiting or excluding the "exposed" is the degree that persons, property, or capability that might otherwise be in the mines and subject to harm are kept out of it.

The prominent approaches are identified as individual events in the Event Logic Tree. Each is mutually exclusive from the other.

25.1 Limit Access to the Mine

Limiting access to the mine can be by a prohibition on entry of persons, property, or operations into the mine. It can include the relocation of an essential process outside the mine as a surface operation, etc.

26.1 (Limit Access to Mine) at All Times

26.2 (Limit Access to Mine) at All Times of Specific Conditions, Threats or Potentials

Examples would include clearing of the mine upon the discovery of a hazardous condition such as unacceptable methane concentration or the undertaking of some specifically dangerous operation such as under certain blasting conditions.

25.2 Limit Access or Concentration of "Exposed" in Specific Areas of Mine

The prime example is the prohibition of entering under unsupported roofs. Other examples might include prohibition of or limitation of access to abandoned areas, limitation of the number of persons in specific work teams, etc.

26.3 Limit Access or Concentration to Specific Areas (at all times)

26.4 Limit Access or Concentration in Specific Areas at Times of Specific Conditions, Threats, or Potentials

25.3 Evacuate in Case of Potential Threat

The removal or evacuation of persons at the time of threat such as discovery of fire. It may consist of removal of all persons or removal of those persons who are either specifically endangered or do not contribute to the control of the threat.

CHAPTER 12 - SAFEGUARDING "EXPOSED" BRANCH (Figure 10)

24.2 Safeguard "Exposed" from Given Threat

"Exposed" is any person, property, or production capability whose harm will reduce the degree of accomplishment of the objectives in Event 1.0. The specific "Exposed" covered in this event represents all the potential "exposed" that is not excluded or limited by Event 24.1. The threat is that which is residual from the result of the degree of failure of Event 13.1, Control Threat.

Each of the events in this branch are functionally dependent on all or the applicable portion of Functional Branch G.

Gate 24.2 - The degree of success in safeguarding the "exposed" from a given threat is the sum of the degree of success in protecting the "exposed" in their work place plus the degree of success of relocating the "exposed" to in-mine refuge areas plus the degree of success in evacuating the "exposed" from the mine.

Functional Branch G, Factors Controlling Protection of "Exposed" (Figure 14)

The functional factors related to protection of "exposed" involve a multi-variant relationship between the total threat (described in terms of extent, intensity, and severity resulting from the degree of success in 13.1 (G-1)), and the avoidance of harm by the "exposed" given that threat (G-2).

The ability to avoid harm is in turn a multivariant function of the tolerance of the "exposed" (in the case of humans, their ability to survive and/or function, in the case of physical property the ability to withstand damage under the given degree of exposure) (G-3), and the positions of the "exposed" relative to the position of the threat (G-10). The position of "exposed" in turn is a function of his ability to move (G-4) and movement actions that use that ability (G-11).

The ability to move (G-4) is a function of the physical capability of the "exposed" to move (or be moved if the "exposed" is inanimate) (G-5), and the fire safety characteristics of the movement route (G-6). The fire safety characteristics of the movement route (G-6) can be described as functions of the safety of the access from the position of the "exposed" to the route (G-7), the capacity or capability of the route to handle the "exposed" (G-8), and the security of the route (or place of protection if such a place is involved) against the intrusion of fire products (G-9).

The security of the route or place can be determined through events that are the same as the events described in Gate 16.5, Control by Confinement if the objective of that gate is revised from "Extent of Burning" to "Extent of Intolerable Conditions".

The movement actions (G-11) using the ability to move is a combined function of the cue generation (initiation of information that a threat is present- e.g., alarm, smoke, word of mouth, etc.) (G-12); the cue reception (the transmission of the signal into understood and knowledgeable information to the responding person or device) (C-13); the manner in which the person or responding equipment receives and analyzes that information and makes a safeguarding decision from it (the decision of concern is the safeguarding action decision resulting in the degree of physical movement and the route of such movement) (G-14); and finally, the actual physical act of movement (G-15). The series of functional factors G-12 through G-15 are sequential in occurrence.

25.4 Provide Protection in Place

Protection in place is defined as the provision of protection in the normal work place or other location of the "exposed" without the necessity of relocation to a specific area. Protection in place can include that type of protection which is conditional on the location and degree of the threat (i.e., a place may be appropriately protected when the threatening fire is remote and/or barricaded but be unsatisfactory as a place of refuge with a different location or degree of fire exposure). For example, barricaded fires in gob areas may leave the entire rest of the mine adequately protected in place.

The degree of success in providing protection in place is the sum of the degree of success provided by safeguards that provide their protection inherently without any special kind of fire action plus the degree of success achieved from safeguards initiated at time of fire.

26.5 Provide Inherently Safeguarded Place

Inherently safeguarded places are those that provide their protection without the need for any adjustments at the time of fire. A prime example of this is a fixed fire resistive barrier. The degree of safeguarding of the place must be sufficient to prevent harm, but the safeguarding may be either of a temporary nature whereby the place may have to be evacuated at some level of threat or, the place may be designed to be tolerable for the duration of the maximum possible threat. The degree of success is a function of this quality and the level of threat.

This is an End Event in the Event Logic Tree as drawn.

26.6 Threat Initiated Safeguard

To the degree that safeguards are not inherent, they may be of a type that is initiated at the time of fire. Prime examples would include automatic closing barriers or the erection of temporary stops or barriers by miners. As with

the inherent safeguard, they may provide temporary or limited security or may be designed to provide tolerability for the duration of the potential fire.

This is an End Event in the Event Logic Tree as drawn; however, in addition to Functional Branch G (which applies to all of the events in this branch), Functional Branch H outlines factors controlling the success of threat initiated safeguards.

Functional Branch H, Threat Initiated Safeguards (Figure 14)

Active systems are fire safety systems that perform their function by responding and performing in a different mode at time of fire than in their normal non-fire condition. The functional requirements for such systems are that they must respond when called upon (H-1), and upon response must perform their essential function (H-2). The functional control of response capabilities are identical to those in the sub-branch, Response, of Functional Branch D.

The performance requirements vary according to the type of performance necessary but relate in each case to functional entities covered under threat control such as Functional Branch F, where a barrier is expected to exclude fire products; Event 15.4, covering the management of product movement; Event 15.5, covering control of oxygen depletion, etc.

25.5 Relocate "Exposed" to In-Mine Refuge Areas

Relocation to in-mine refuge areas involves emergency movement of the "exposed" from their normal place in the mine to some safeguarded place. The safeguard may provide temporary or duration of fire tolerability. The functional requirements of both Functional Branches G and H apply.

This is an End Event in the Event Logic Tree.

25.6 Evacuate Mines

Evacuation is the removal of the "exposed" through a safe area external to the mine. In terms of life safety, it is the primary means of protection of the exposed. Functional Branch G applies in this case.

This is an End Event in the Event Logic Tree.

CHAPTER 13 - STATES AND TRANSITIONS

In recent years a combined concept of the interrelationship of people, the environment, and fire has emerged. This concept was introduced by Nelson, in terms of the fire environment in 1972 [1] and expanded by him to include the interrelationships of fire and people in 1977 [2]. Elements of the approach are fundamental to the Building Fire Model developed under the auspices of the National Fire Protection Association [3]. The state-transition concept is felt to allow better focus on the worth and impact of prevention, control, or protection strategies.

This concept is based on the premise that:

1. Within any given environment (mine, building, or other location), fire behavior and the behavior of persons involved can be expressed as a series of describable behavior patterns connected together to form sequences.

2. The fire behavior and people behavior sequences are separate but can be (and often are) inter-reacting with each other.

3. The separate behavior patterns that make up the sequence consist of individual periods during which there is a consistency of the form of fire growth and/or inter-play between fire and its environment, or of the response of individuals or groups of individuals to the resulting threat. These periods of consistent behavior are referred to as states. In some texts, the terms "realms" or "regimes of burning" are also used

in reference to states of fire. In human behavior research, the term "episode" is more commonly used than states to describe periods of human behavior. The term episode is used for that purpose.

4. Each state (or episode) starts and ends with a change in response to the environment of sufficient magnitude to cause a change in the patterns of behavior. In the fire behavior sequence, these are referred to as critical events. In the human behavior sequence, they are referred to as decisions or decision points.

5. Many of the states of fire behavior are not static but vary with time in the state. In such situations, the degree of threat or harm can vary according to the period of time within the state. The rate of variation, however, will differ from state to state. The fire behavior sequence, as outlined herein, is such that generally an increase to a higher numbered state constitutes an increase in both the level of threat and the rate of increase of threat for a period of time in that state.

6. At any instant in the combined fire behavior/human behavior sequence there is a single overall level of fire safety performance (or conversely fire risk or harm). This level is represented by the top event (Event 1.0, Fire Safety Performance) in the Event Logic Tree.

7. The fire safety performance is enhanced by the degree to which the fire safety systems and efforts to maintain the fire in a lower order state succeed, and the degree to which the period of advance into any more destructive or threatening state is limited. Similarly, those objectives related to the well-being of persons are enhanced by the degree to which the human behavior episodes or activities avoid the simultaneous occupancy of a space by intolerable fire threats and humans.

8. The events in the Event Logic Tree govern the states that a fire is in, the transitions between states, the advance within a state, and the

human behavioral sequence. In general only a portion of the events are operative in any state or involved in any transition. Those factors that control the situation at any moment are referred to as dominant factors for that state or transition. In general, the entry of a new dominant factor results in a state change.

Fire Behavior Sequence

The choice of states depends on the level of detail desired in examining the fire condition. For the purposes of this study, six major states of fire have been selected and have been sub-divided into their most important sub-states. The six basic states are:

State 0, Non-burning
State 1, Development on First Ignited Fuel
State 2, Multi-item, Fuel-controlled Burning
State 3, Ventilation Controlled Burning
State 4, Multi-spacial Involvement
State 5, Mine Fire

a. State 0, Non-burning

This state covers all conditions when fire does not exist. The sub-states cover the range of conditions from the normal or static situation where no fire threat exists through the varying levels of precursor situations in which the potential of fire initiation increases through heating or chemical reactions of potential fuel. The critical events or transitions from the non-burning state include the various types of fire initiation that may occur. The actual transition from non-burning to a burning state may be defined differently under different circumstances. Most of these circumstances are listed in the critical events for transition from the state. It is considered legitimate to define fire initiation by any of these critical events according to the needs of the user of the concepts. It is essential, however, that once such a

decision has been made that this working definition be maintained or that any variation be clearly identified.

The sub-states of State 0, Non-burning, identified for the purposes of this paper are:

0.0 Static

0.1 Preheat/self heating

0.2 Vaporization (of hydrocarbons)
- 0.2.1 Lean
- 0.2.2 In explosive/flammable range
- 0.2.3 Rich

0.3 Pyrolysis (without combustion)

The critical events governing transition from State 0 include:

A.1 Supported smoldering
- A.1.1 To State 1
- A.1.2 To State 2

A.2 Self-sustained smoldering
- A.2.1 To State 1
- A.2.2 To State 2

A.3 Supported flaming
- A.3.1 To State 1
- A.3.2 To State 2

A.4 Self-sustained flaming
- A.4.1 To State 1
- A.4.2 To State 2

A.5 Explosion

A.5.1 Non-disrupting - No subsequent ignitions - To State 0

A.5.2 Non-disrupting - Subsequent ignitions to States 1, 2 or 3

A.5.3 Physically disrupting of spacial barrier - No subsequent ignitions - To State 0

A.5.4 Physically disrupting of spacial barrier - Subsequent ignitions, to States 1, 2, 3, 4 or 5

b. State 1, Development on First Ignited Fuel

This state covers the development of fire from the initiation of burning to the point where the fire either terminates or extends to one or more additional items (or involves the entire mine or section of the mine in a ventilation controlled fire). By definition, this state is relegated to fuel controlled burning with little or no influence on the burning item as a result of energy feedback from the overall surrounding environment. In this state, not only the basic physical properties of the material, but its shape and form and its proximity to other ignitable material play important parts.

The sub-states of State 1, Development on First Ignited Fuel include:

1.1 Single surface spread

1.1.1 Single-dimensional

1.1.2 Two-dimensional

1.1.3 Three-dimensional

1.2 Multi-surface spread

1.2.1 Single-dimensional

1.2.2 Two-dimensional

1.2.3 Three-dimensional

1.3 Gas phase propagation

1.4 Steady state

1.5 Decay

The critical events involving transition from State 1 to an additional state include:

B.1 Ignition of additional item - fuel controlled burnings

B.1.1 Individual item(s) (separate fuel package(s)) - to State 2

B.1.2 Combustible surface(s) - to State 2

B.1.3 Combustible gas/vapor/dust mass

B.1.3.1 Non-disrupting - to State 3

B.1.3.2 Physically disrupting of spacial barriers- to State 4

B.2 Transfer to ventilation controlled burning - to State 3

B.3 Extend to multi-compartment burning - to State 4

B.4 Decay to State 0

c. State 2, Multi-item, Fuel-controlled Burning

This state is an extension of State 1 in which the critical event involved has resulted in the spread of fire between items, increasing the basic fuel bed in both quantity of fuel and extent, but has not involved a change from fuel controlled burning or reached an intensity that produces a significant energy feedback from the surrounding environment.

The sub-state of State 2 include:

2.1 Individual burning (repeat State 1 for item(s) 1 to N)

2.2 Coalesced burning (repeat State 1 for coalesced fuel package)

The critical events governing the transitions from State 2 to another state include:

C.1 Transfer to ventilation controlled burning to State 3

C.2 Decay to State 1

C.3 Extend to multi-compartment burning - to State 4

C.4 Decay to State 0

d. State 3, Ventilation Controlled Burning

Ventilation controlled burning is that state of fire where the burning rate is controlled by the rate at which the necessary oxygen for combustion can be obtained an entrained in the effluent products liberated by the feedback energy from flame, hot gases, or heated surfaces to exposed fuel. The transition from fuel controlled burning to ventilation controlled burning would normally be expected to force evacuation of all or part of the mine and likely involve the coal seam.

The sub-states within State 3, Ventilation Controlled Burning include:

3.1 Steady pyrolysis rate

3.2 Decreasing pyrolysis rate

- 3.2.1 Constant extent of burning area
- 3.2.2 Decreasing extent of burning area

3.3 Increasing pyrolysis rate

- 3.3.1 Constant extent of burning area
- 3.3.2 Increasing extent of burning area

The critical events governing the transition from State 3 to another state include:

D.1 Inter-spacial ignitions - Extend to State 4

- D.1.1 Unsupported discrete ignition(s) (apply State 1 or 2 in new spaces)
- D.1.2 Energy supported discrete ignition(s) (apply States 1 or 2 in new space(s))
- D.1.3 Massive energy supported general ignition (apply State 3 to new space(s))

D.1.4 Structural failure (extend space to include newly included area(s))

D.2 Recede to fuel controlled burning of 1 to N items - to State 2

D.3 Recede to fuel controlled burning of item - to State 1

D.4 To State 0

e. State 4, Multi-spacial Involvement

Multi-spacial involvement covers the spread of fire from space to space through unprotected openings or through failure of the fire stopping capabilities of physical barriers. It is expected that advance of fire into State 4 will usually involve ventilation controlled burning in the exposing space. Sub-state 4.1 covers the situation of advance of only ignition sources without transfer of the full energy or joining of the newly involved spaces into a single coalesced fire. In such cases, fire in the additional spaces develops relatively independently of the initial fire. Sub-state 4.2 covers the situation of advance of a full flame front where the additional spaces join the initial fire in one single ventilation controlled incident.

The individual sub-states of the State 4, Multi-spacial Involvement, include:

4.1 Separate burning (independent repetitions of states 1 through 3)

4.2 Coalesced burning (joining of burning spaces into single coalesced fire)

The critical events marking transition to other states include:

E.1 Transfer to mine fire - Extend to State 5

E.2 Decay

E.2.1 To State 3

E.2.2 To State 2

E.2.3 To State 1

E.2.4 To State 0

f. State 5, Mine Fire

This state is defined as a fire which so involves the mine as to have reached a steady state of burning and essentially driven all occupants to the surface where the mine cannot be re-entered until the fire decays in some manner to a lower level state.

Human Behavior Sequenced

The sequences of states or episodes of human behavior do not necessarily follows progressively increasing levels of safety or potential of harm. Rather they consist of actions chosen by those involved (as a result of experience, training, or ad hoc judgement) that they believe best for their needs or objectives at the specific time of decision. The basic objective in protection of humans is always the avoidance of occupancy of the same space at the same time by people and by conditions intolerable to people. In fire situations, the fire effect may be moving or may be concentrated in a limited area. The humans involved may or may not be mobile according to the conditions they face and their safety may or may not be dependent upon their actions. In some cases, they may be able to undertake actions to directly mitigate the threat. In other cases, they may only be able to undertake actions to escape or avoid the threat. The number and type of actions undertaken by people in fire situations are manifold. The following general classifications, however, are proposed as the episodes which can be used to classify the physical acts under Functional Element C-15 of the Event Logic Tree. For the purposes of this paper, these episodes are:

Episode A, No Action

Episode B, Investigate

Episode C, Attack

Episode D, Alarm

Episode E, Flee/Escape

Episode F, Rescue

a. Episode A, No Action

No action is used to define any situation where persons do not undertake any activity relevant to protection of themselves or others or to control of fire. Such actions may include continuing to mine or haul coal, attending to other business, or undertaking some more pressing need (e.g., maintaining life support ventilation to portions of the mine unrelated to the fire).

b. Episode B, Investigate

Investigation includes all of those actions where a person receiving a cue seeks to remove ambiguities or to gain advice or instruction before taking further action. Fire experience indicates that humans tend to assume that risk indicators are indicative of their lower, rather than their higher potential. Often, they seek to remove ambiguities from indistinct or confusing cues or signals, and tend to seek reinforcement before taking unusual actions, even those potentially for their own or their fellow workers well being or for protection of the facility.

c. Episode C, Attack

This episode covers any activities aimed directly at terminating the fire or controlling or mitigating its impact on either people or property. Specific actions would include activities such as, application of extinguishment, closing of barriers to control smoke, or removal of fuel from a fire source.

d. Episode D, Alarm

This episode includes all of those activities in which the existence or the state of a threat is communicated by direct human contact, voice or symbolic alarms, or other means. The alarm may be given to warn of danger, initiate self protection measures, summon emergency assistance, or other purposes.

e. Episode E, Flee/Escape

This episode includes all activities directed at escaping the threat of fire. It includes leaving the mine or taking refuge within the mine.

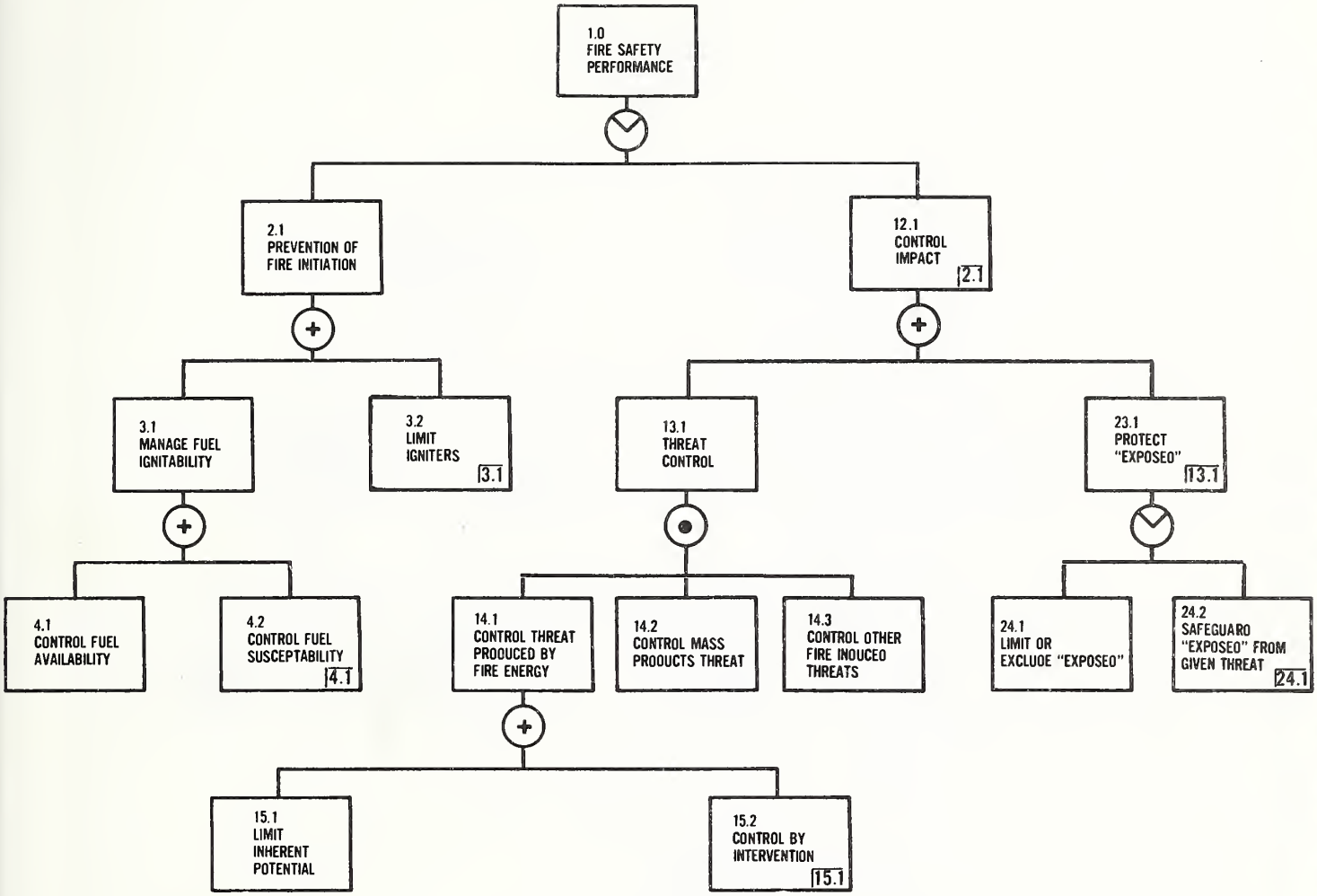
f. Episode F, Rescue

This episode includes all activities involved in assisting others. It includes those in which a miner assists another in escaping or taking refuge as well as the more formal rescue teams that may enter a mine after the fire has developed to a more advanced fire state.

General Mode

Figure 15 outlines a general model of the interrelationships between the fire behavior sequence and the human behavior sequence. As indicated by this model, fire behavior is looked upon as a series of independent states connected by critical events. Human behavior is a similar series of independent episodes connected by decisions. The two sequences influence each other with stimuli (cues) that flow from the fire behavior to the human behavior sequence causing action or impacting on the well being of humans. The flow of stimuli is caused by the fire behavior sequence and is proportional to it but entirely separate in its functional aspects. Flow from the human behavior sequence to the fire sequence is however, in the form of impacting actions. The type of impacting action can be any of the behavioral episodes that cause a change in the fire or the ensuing fire threat. Impacting actions can be to the benefit of the overall fire safety performance

where they involve or result in intervention in the fire development. Conversely, they can be detrimental to the objective where the actions result in increasing the threat. Typical of such detrimental action might be the opening of a door in or the breaking through stopping in a manner that either diverts the air supply or allows smoke propagation to areas that would not otherwise have been affected.



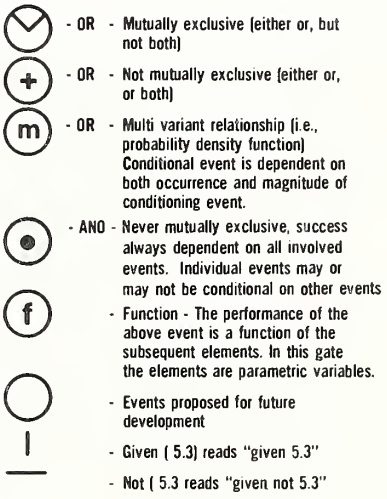

- OR - Mutually exclusive (either or, but not both)
- OR - Not mutually exclusive (either or, or both)
- OR - Multi variant relationship (i.e., probability density function) Conditional event is dependent on both occurrence and magnitude of conditioning event.
- AND - Never mutually exclusive, success always dependent on all involved events. Individual events may or may not be conditional on other events
- Function - The performance of the above event is a function of the subsequent elements. In this gate the elements are parametric variables.
- Events proposed for future development
- Given (5.3) reads "given 5.3"
- Not (5.3 reads "given not 5.3"

Figure 1. General (overview) Event Logic Tree

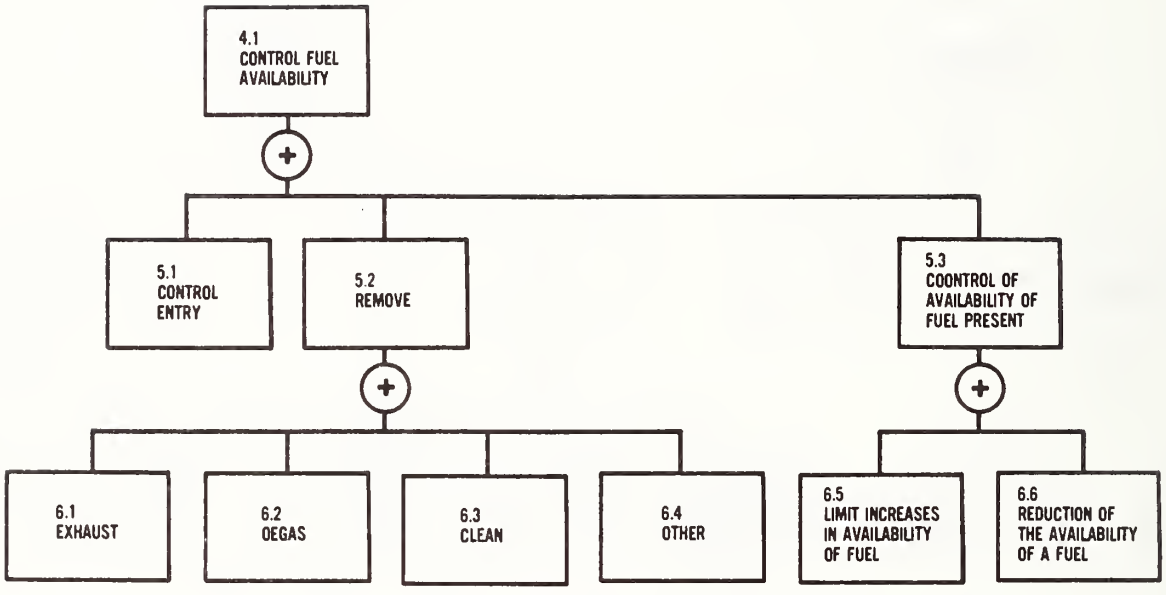


Figure 2. Control Fuel Availability Branch

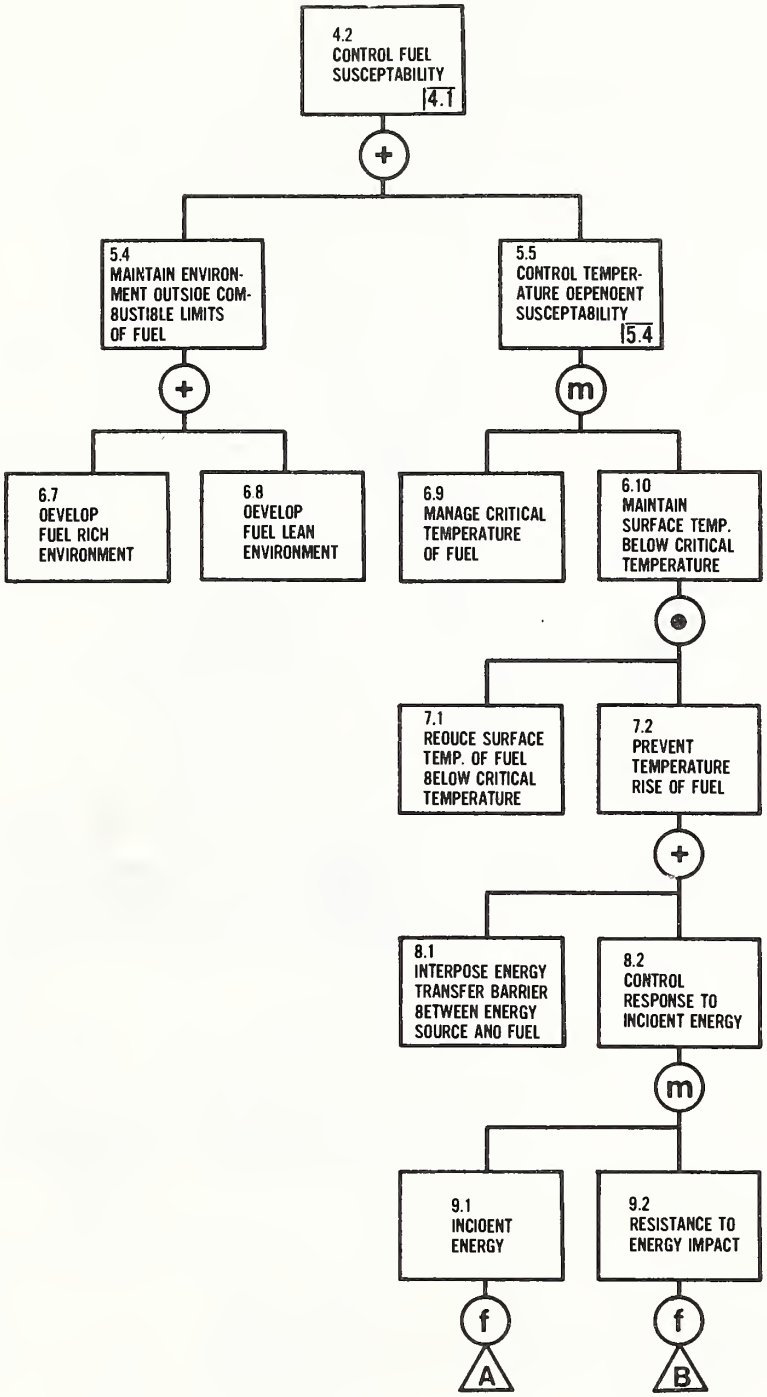


Figure 3. Control Fuel Susceptibility Branch

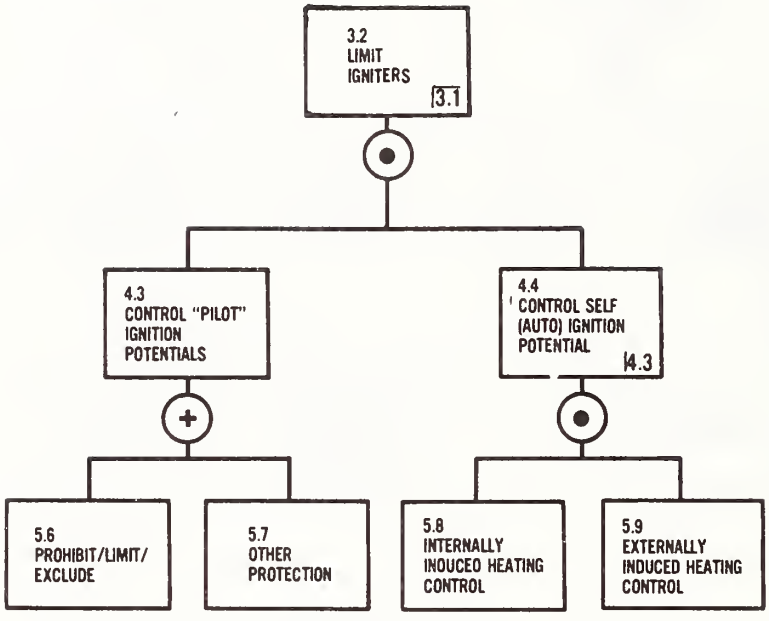


Figure 4. Limit Igniters Branch

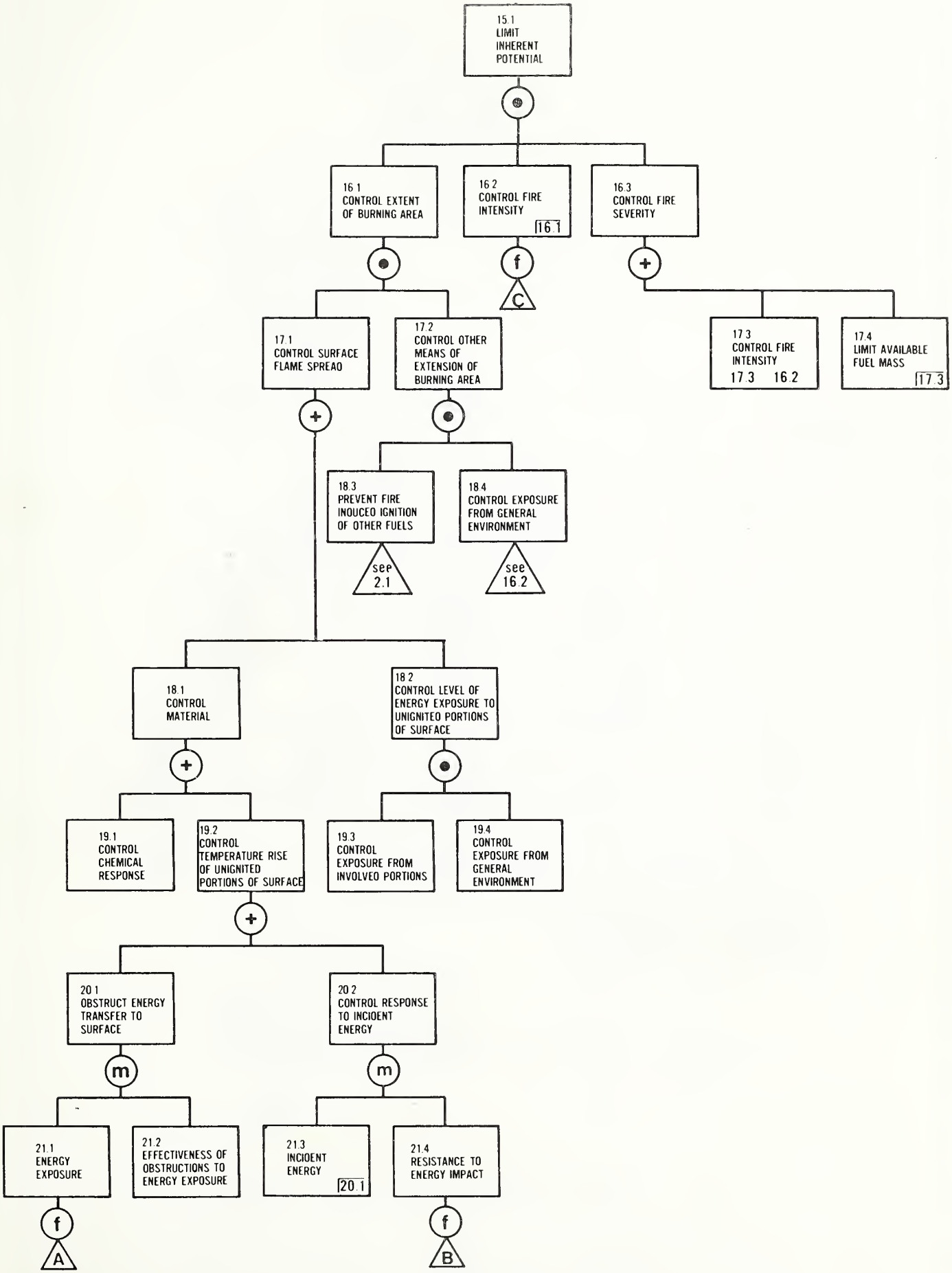


Figure 5. Limit Inherent Potential Branch

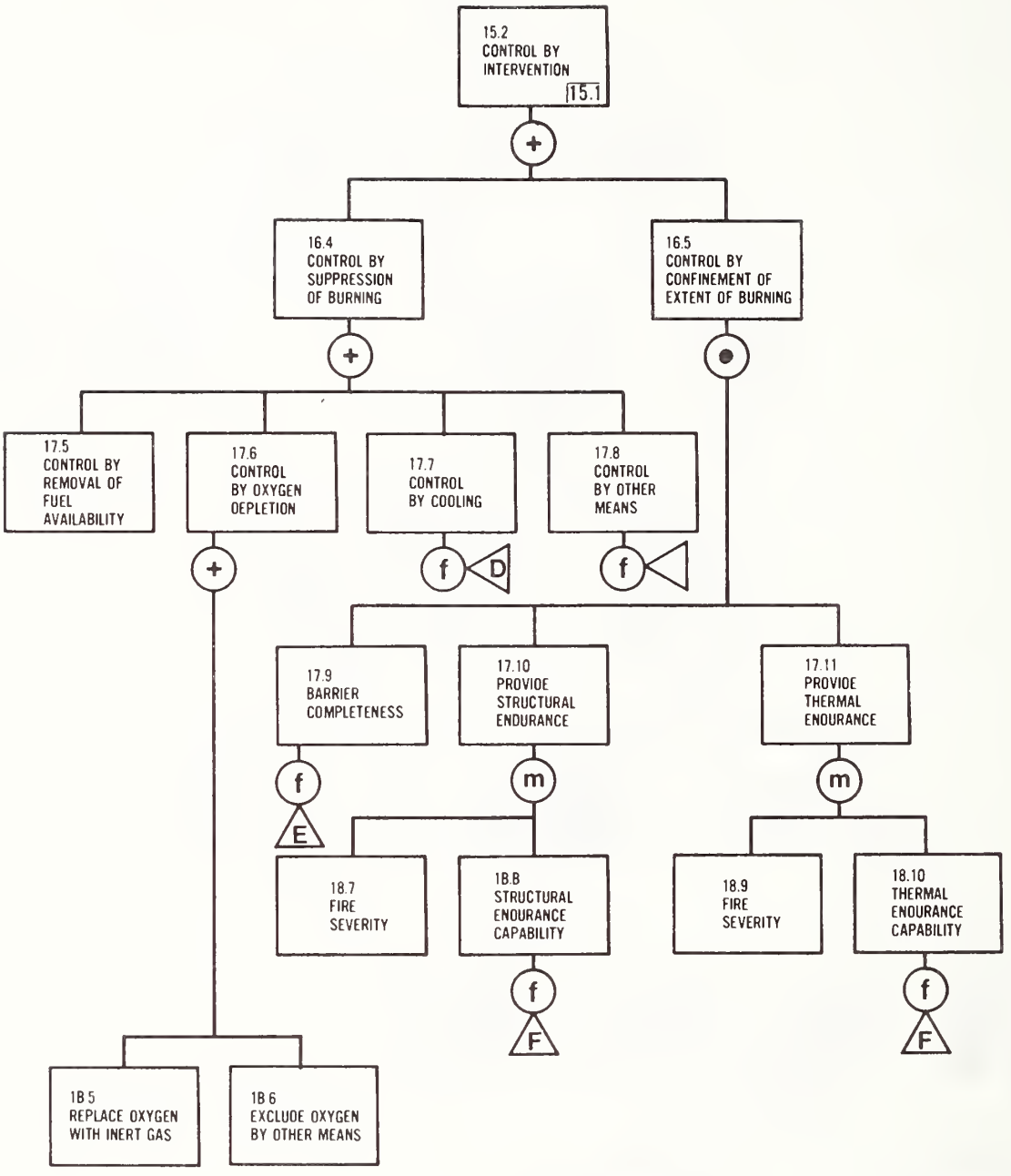


Figure 6. Control by Intervention Branch

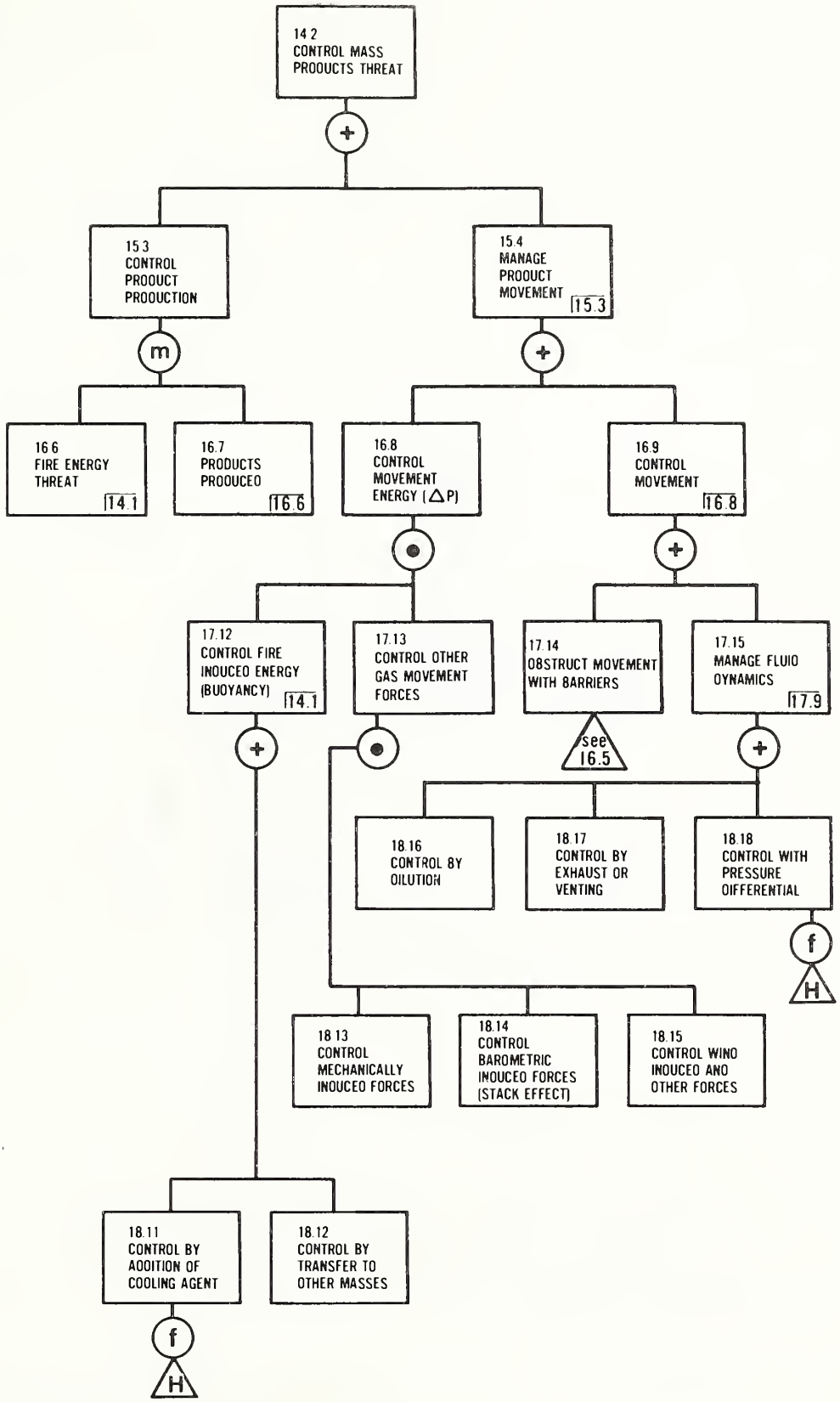


Figure 7. Mass Product Threat Branch

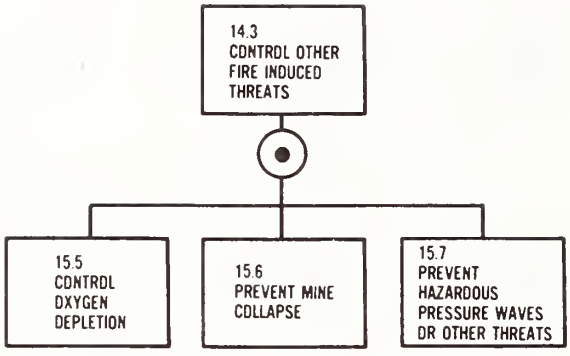


Figure 8. Control Other Fire Threats Branch

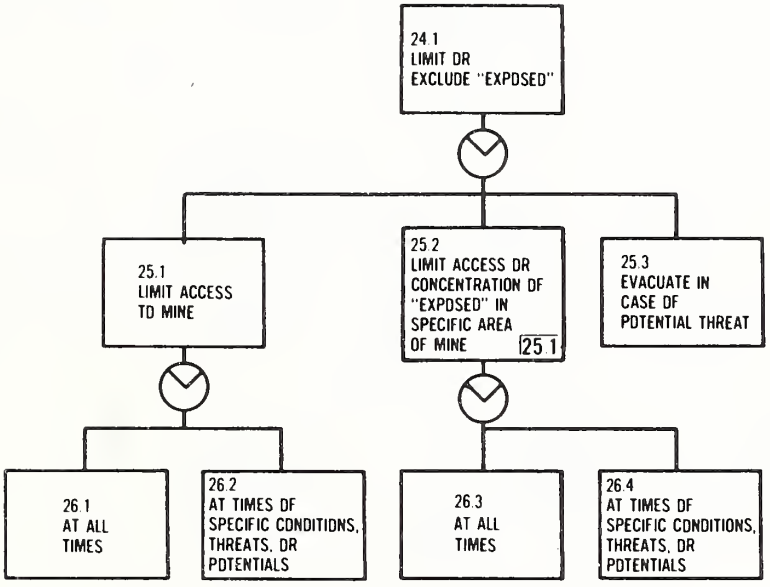


Figure 9. Limit of Exclude "Exposed" Branch

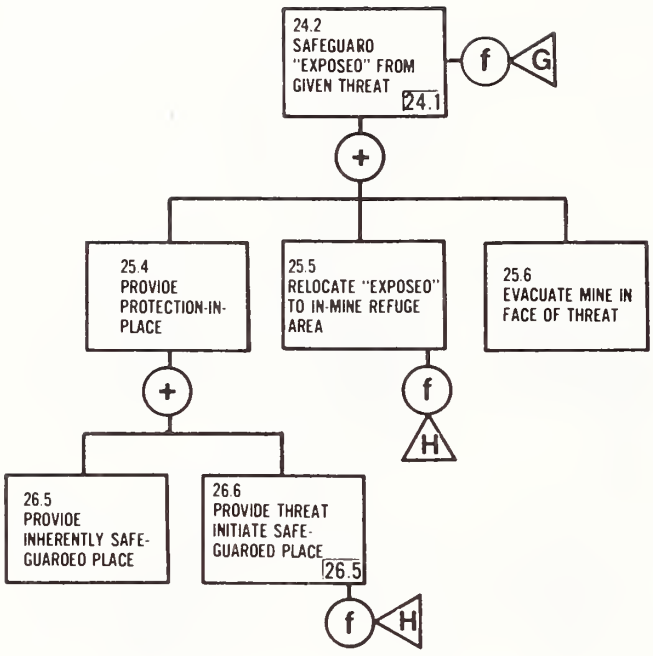


Figure 10. Safeguard "Exposed" from Given Threat Branch

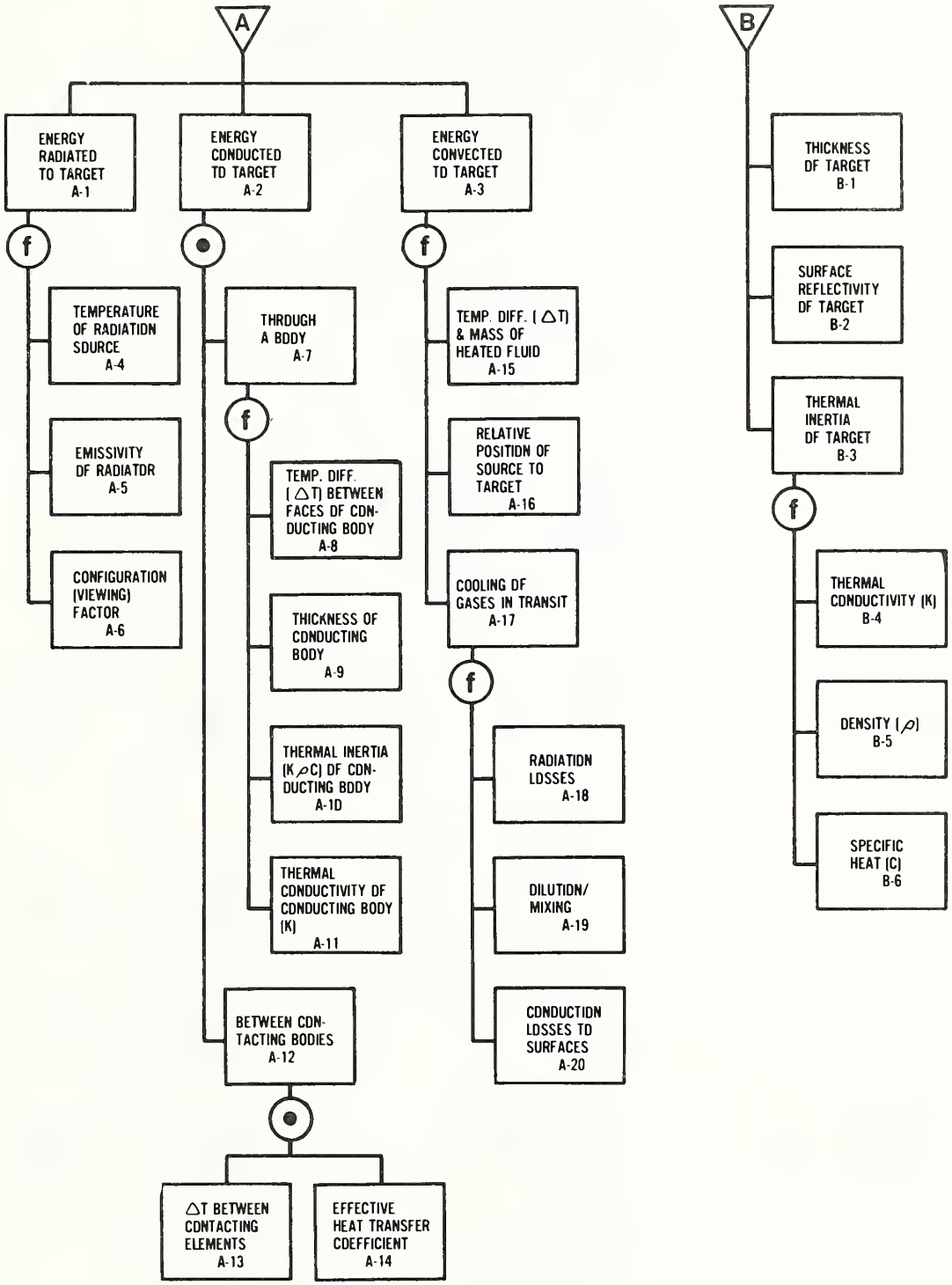

A
ENERGY RADIATED TO TARGET A-1
ENERGY CONDUCTED TD TARGET A-2
ENERGY CONVECTED TD TARGET A-3
f
TEMPERATURE OF RADIATION SOURCE A-4
EMISSIVITY OF RADIATOR A-5
CONFIGURATION (VIEWING) FACTOR A-6
THROUGH A BODY A-7
TEMP. DIFF. (△T) BETWEEN FACES OF CONDUCTING BODY A-8
THICKNESS OF CONDUCTING BODY A-9
THERMAL INERTIA (KρC) OF CONDUCTING BODY A-10
THERMAL CONDUCTIVITY OF CONDUCTING BODY (K) A-11
BETWEEN CONTACTING BODIES A-12
△T BETWEEN CONTACTING ELEMENTS A-13
EFFECTIVE HEAT TRANSFER COEFFICIENT A-14
TEMP. DIFF. (△T) & MASS OF HEATED FLUID A-15
RELATIVE POSITION OF SOURCE TO TARGET A-16
COOLING OF GASES IN TRANSIT A-17
RADIATION LOSSES A-18
DILUTION/ MIXING A-19
CONDUCTION LOSSES TO SURFACES A-20
B
THICKNESS OF TARGET B-1
SURFACE REFLECTIVITY OF TARGET B-2
THERMAL INERTIA OF TARGET B-3
THERMAL CONDUCTIVITY (K) B-4
DENSITY (ρ) B-5
SPECIFIC HEAT (C) B-6

Figure 11. Functional Branches A and B

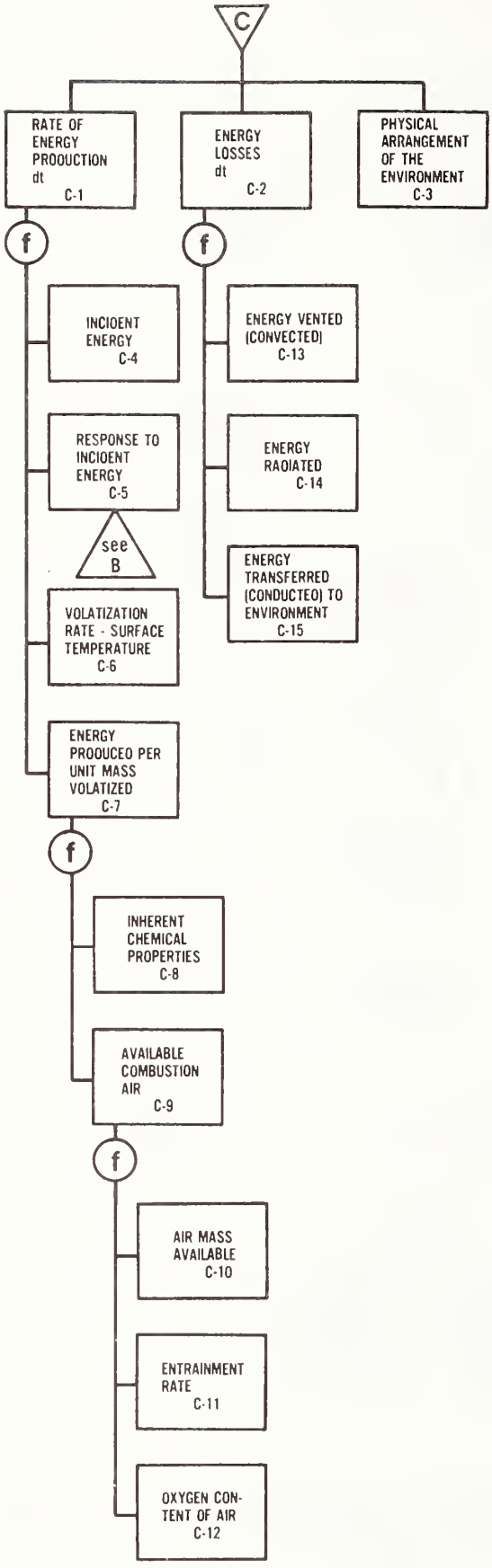


Figure 12. Functional Branch C

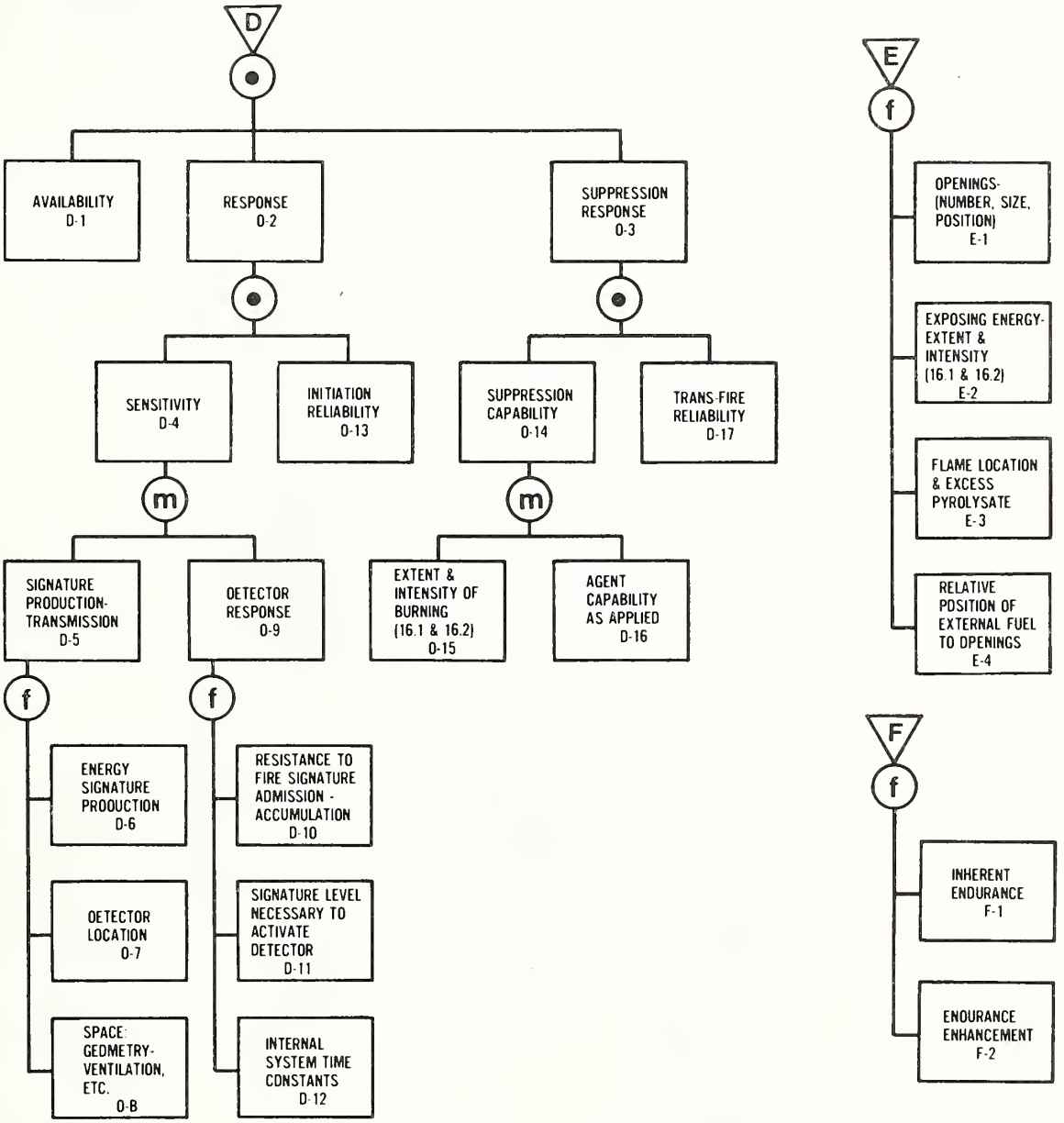


Figure 13. Functional Branches D, E, and F

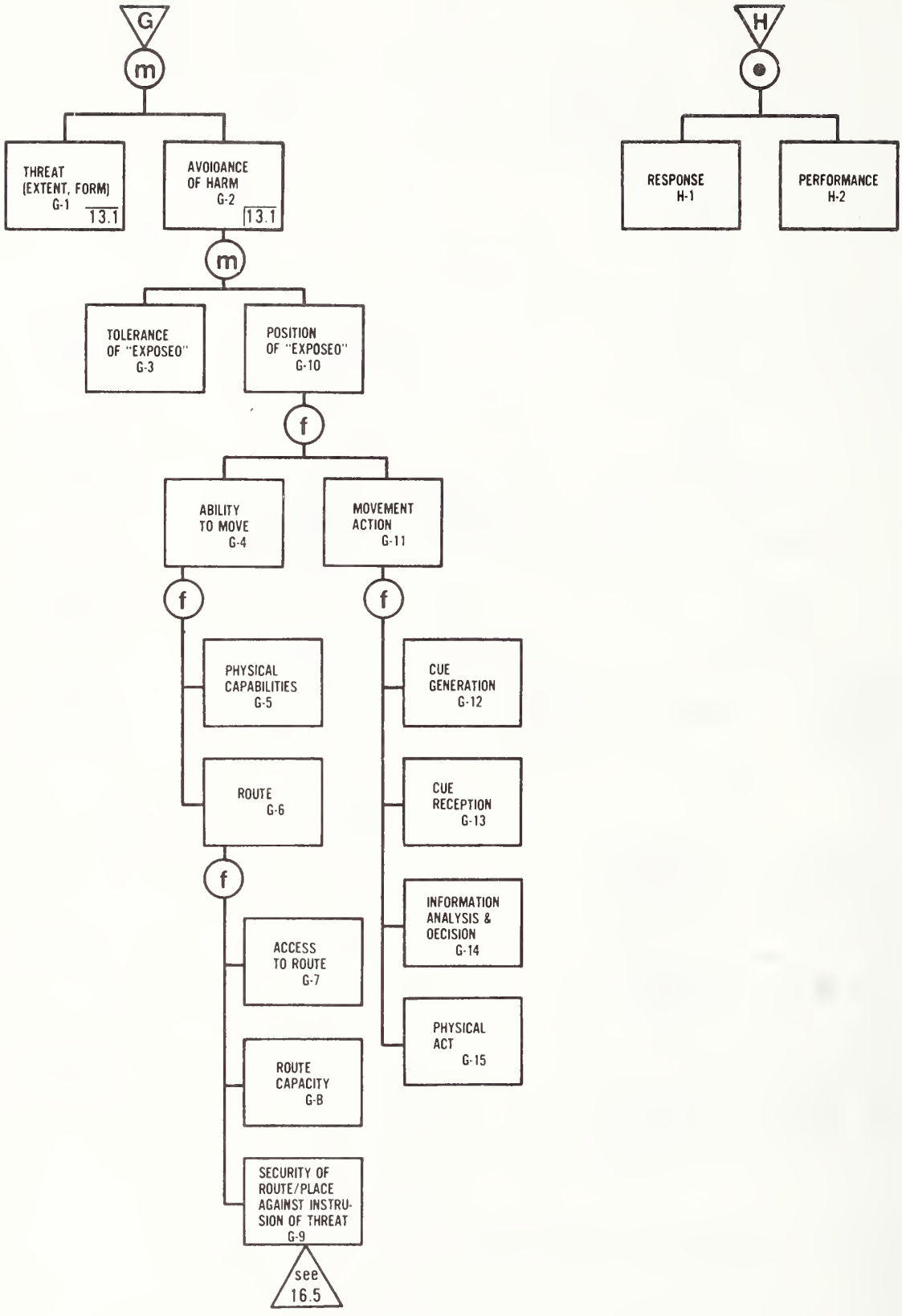


Figure 14. Functional Branches G and H

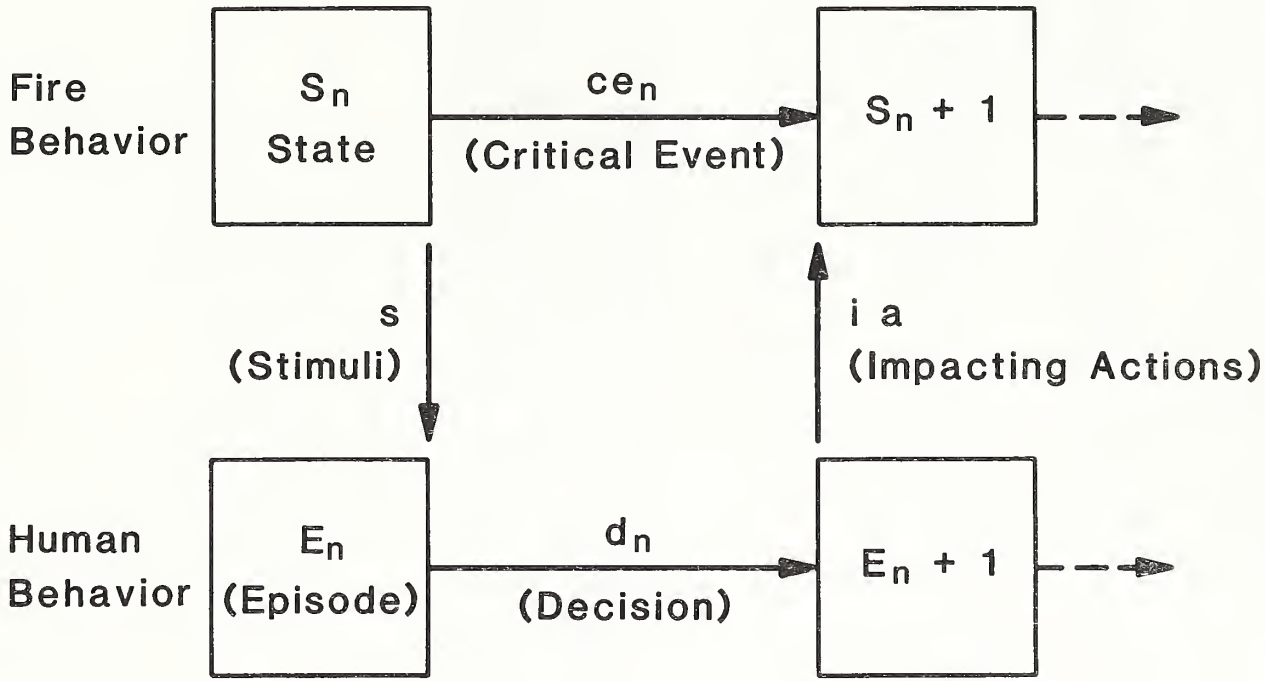


Figure 15: General Model of Interrelationships Between States and Episodes

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A quantitative description of a fire safety analysis sytem for a coal mine. An event-logic tree and a state transition model are presented. This report is also presented as Appendix D of NBSIR 86-3425, The Development of a Fire Evaluation System for Underground Coal Mines.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Coal mines; event logic tree; fire hazard; fire risk; fire safety; state transition.

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